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Mathematical Model of Electrostatic Precipitation for the Texas Instruments Programmable 59 Calculator

Southern Research Inst., Birmingham, AL

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

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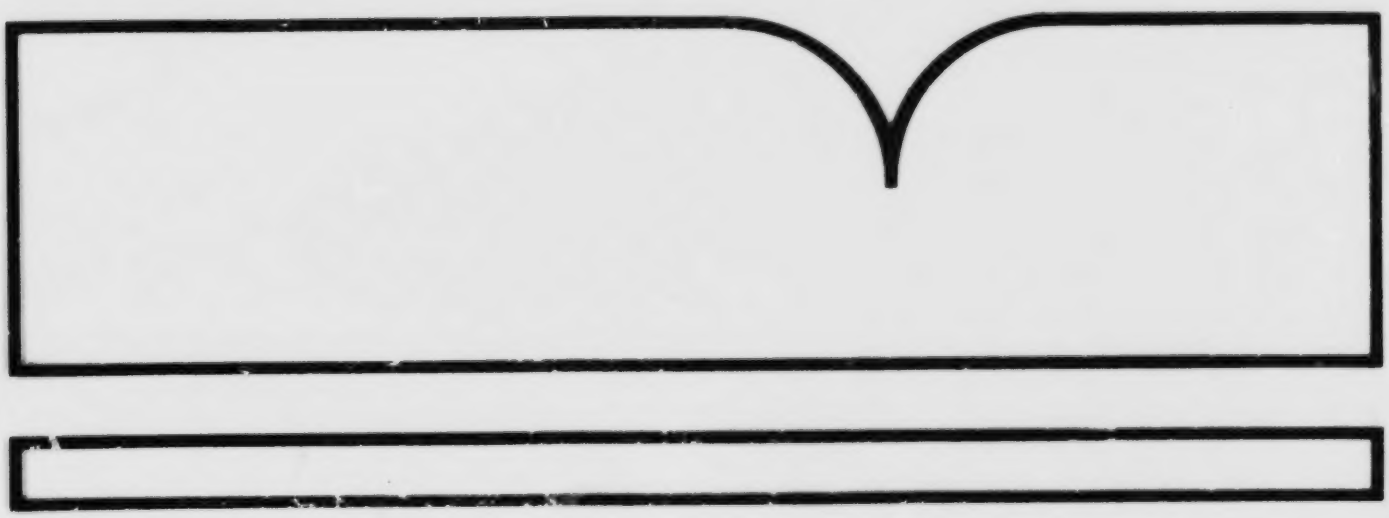

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A MATHEMATICAL MODEL OF ELECTROSTATIC PRECIPITATION FOR THE TEXAS INSTRUMENTS PROGRAMMABLE 59 CALCULATOR

by

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16. ABSTRACT The report describes a version of EPA's electrostatic precipitator (ESP) model suitable for use on a Texas Instruments Programmable 59 (TI-59) hand-held calculator. This version of the model allows the calculation of ESP collection efficiency, including corrections for non-ideal effects and rapping reentrainment in five size bands. Program input data and the individual and total collection efficiencies are printed on a TI Thermal Printer. This model is described in detail, including program steps for its use. This version and the full-scale model are compared.

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Efficiency		

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ABSTRACT

A version of the Environmental Protection Agency's electrostatic precipitator model suitable for use on the Texas Instruments Programmable 59 hand calculator has been prepared. This version of the model allows the calculation of the precipitator collection efficiency including corrections for non-ideal effects and rapping reentrainment in each of five size bands. Program input data and the fractional and total collection efficiencies are printed on the Texas Instruments Thermal Printer. This model is described in detail including program steps for the use of the model. A comparison between this version and the rigorous model is also presented.

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SECTION 1

INTRODUCTION

The Environmental Protection Agency's (EPA) mathematical model of electrostatic precipitation was first published in 1975.[1] Revision 1 of the model was published in 1978.[2,3] This model has been widely used to study existing electrostatic precipitators (ESP's) and to predict size requirements and performance levels for new precipitators. However, a computer of the size required to operate the model may not be available to some individuals who desire to use the model. Therefore, EPA has sponsored the development of a reduced version of the ESP model which may be operated on a programmable hand calculator. This report describes a version of the ESP model which was developed for use on the Texas Instruments Programmable 59 calculator. The theory of ESP operation on which the model is based and the assumptions used are explained in depth in reference 2 and will not be repeated here. The user is urged to obtain reference 2 for use with this report in order to understand the procedures.

The Texas Instruments Programmable 59 calculator offers the capability of writing to and reading from magnetic cards. This feature allows a lengthy program to be entered into the unit in one step. This is a necessary function as a program of the complexity of the ESP model requires the reading of many magnetic cards. In addition, the use of the accessory printer for the Programmable 59 allows

the creation of a permanent record for each set of ESP operating conditions modeled. Another advantage of this calculator is its capability to vary the memory partition between data storage and program steps to suit a particular program. For the ESP model, 70 data storage locations are required which limits the number of program steps which can be entered to 400. In order to fit into 400 spaces, the program is divided into 8 sections, some of which must be read into the calculator more than once to complete the calculation.

The full scale ESP model allows the user many options in the type of data which may be used and in the types of calculations which will be performed. Due to the limited size of the Programmable 59, the options are severely limited. The data must be in one prescribed format. The calculation of the ideal collection efficiency uses the estimation procedures rather than the more rigorous calculations available on the full scale model. The program output has been curtailed to efficiency in each size band and overall collection efficiency. These are printed for the ideal case, the ideal case corrected for several non-ideal conditions not including rapping losses, and the corrected case including rapping losses. As an option, the fraction of the effluent appearing in each size band may be printed for the two corrected conditions to serve as estimates of the particle size distributions at the outlet of the precipitator.

The following sections of this report completely describe the structure and use of the ESP model for the Programmable 59 calculator. A description of the 8 sections of this program and their printed output appears in Section 4. Section 5 defines the

required input data in order of use. A detailed program operation guide is presented in Section 6. Appendix 1 contains detailed flowcharts for all sections of the model. Rather than just stating the variable to be defined in each operation, these flowcharts list complete equations for the defined quantities and the storage locations for each one. The variable names used are the same or very similar to the ones used in the full scale model. Appendix 2 defines all of the variables. The program listings required for programming the calculator are presented in Appendix 3. Adjacent to the listing of the program steps are step numbers to serve as a check that no steps be omitted. In addition, variable names for many of the quantities are given in brackets so that the listings may be compared to the flowcharts. Appendix 4 contains a map of the locations of variables for all of the sections of the model. Appendix 5 contains a sample program output for a power plant precipitator. A program output for the same plant run with the rigorous model is presented for comparison. Appendix 6 contains a FORTRAN listing of a shortened version of the model in which all of the approximation procedures are used. This version is the equivalent of the Programmable 59 model.

SECTION 2

CONCLUSIONS

The procedure described in this report provides a mechanism for modeling ESP performance on a programmable calculator. The program is limited in that it provides collection efficiency information only. The full-scale model, designed for a large computer, also prints migration velocities, particle charges, outlet size distribution and other data. Of these, only the migration velocities are available in the hand calculator version. They are not printed but may be retrived from the calculator memory. The other variables are not available. Some, such as particle charge, are calculated but are written over by other variables. Others are not calculated at all due to the limited memory size.

Another limitation of the calculator version of the ESP model is that it uses all of the estimation procedures available in the full-scale model. For several calculations, the full-scale model offers the choice of a rigorous calculation for maximum accuracy or an estimation to save time. In the calculator version, the limiting factor is memory size, which necessitates the use of the shorter estimations. An additional limitation is the use of only 5 size bands, again due to the limited memory size.

The time required to model the 3 section ESP described in Appendix 4 was 37 minutes for the ideal calculation or 51 minutes

for the ideal case plus 3 sets of non-ideal conditions. It required 4 minutes to run the equivalent full scale model on a PDP-15 computer, which is not a fast computer. However, the run time for the PDP-15 does not include the time required to enter the data, which is estimated at 45 minutes. Data entry time is included in the figures shown for the Programmable 59 version. Therefore the times required to run the two versions are comparable. The time required to run the rigorous calculation (rather than estimations) with 16 size bands on the full scale model is 1.25 hours plus 45 minutes for data entry.

In spite of its limitations the calculator version achieves close agreement with the full-scale version, as shown by the example in Appendix 5. For the purposes for which it was intended, the calculation of ESP efficiencies on a programmable calculator, the calculator program performs very well. Therefore, it is a useful tool for ESP model users operating on a low budget, requiring results quickly or desiring only efficiency information.

SECTION 3

RECOMMENDATIONS

This version of the ESP model allows the calculation of ESP efficiencies on a relatively low cost hand held calculator. This serves as a useful function in that it provides the use of an ESP model to people who may not have access to a suitable computer, whether due to high operational costs or to remote location. For the same reason, it is recommended that a study be performed to identify other important programs which may be scaled down to fit on low cost, easily portable programmable calculators.

SECTION 4

THE SECTIONS OF THE PROGRAM

Due to the length of the ESP model, it was necessary to divide the program into 8 sections, each occupying a magnetic card. The number of these which are read into the calculator varies with the desired program output. The minimum number of cards required to run the model is 5: cards 1-4 for the ideal calculation and card 6 for the no-rap corrections. In order to include rapping reentrainment cards 5 and 7 must be added to this. Card 8 may be added if an estimate of the particle size distribution at the precipitator outlet is desired. Once the ideal efficiency calculation has been performed, it need not be repeated to run additional sets of non-ideal conditions. Only cards 5 through 8 need to be reread. A detailed description of the options available and the cards required to obtain them is given in Section 4 of this report. A description of the functions and printed output of each card is given below. The word NEXT is printed at the end of each program segment and signifies that the next card may be read in. An example of program output is shown in Appendix 4 where it is compared to the output of the full scale model.

Card 1 is the equivalent of subroutine LNDIST in the full scale program. This card constructs a particle size distribution histogram for a specified log-normal distribution. The mass

median diameter (mmd) and geometric standard deviation (σ_g) which define the log-normal curve and 6 particle size band endpoints are supplied by the user. The calculator computes and stores the average diameters of five size bands and the fraction of the inlet particulate mass which occurs in each band for later use. The fraction of mass in the 0.01 to 1000 μm size range which has diameters outside the range of the 5 size bands is added to the largest size band. The program steps contained on card 1 occupy 1 card side. The input data are printed.

Card 2 is used to enter data and calculate constants which will be used throughout the rest of the program. The program on card 2 occupies 2 card sides. The input data are printed.

Card 3 is used to enter data which are unique to each electrical section of the precipitator. These include the number of calculation increments, the total collection plate area, the applied voltage, the current and the wire-to-plate spacing. After the calculations for all of the sections of the precipitator have been completed, card 3 is used to calculate the ideal efficiency in each size band and the ideal total efficiency. This card is read in once for each electrical section and once to complete the ideal efficiency calculation. The program material occupies 1 card side.

If LSECT, the first variable read by card 3, is not equal to zero, the input data are printed. If LSECT equals zero, the printer lists the particle diameter (m) and ideal efficiency (decimal) for each size band, followed by the total ideal efficiency.

Card 4 calculates the particle charge and the number of particles removed in each size band for each increment of length in the precipitator section described by card 3. This card is read in once for each electrical section. This is a 2 sided card. However, since card 3 only occupies 1 card side, it is only necessary to read in side 2 of card 4 once. Side 1 must be read in each time as card 3 writes over this portion. There are no data entered in this segment of the program and no printed output.

Card 5 is the same as card 1. The routine is used again at this point so that a particle size distribution for rapping reentrainment may be formed. If no rapping information is desired, this card is omitted. The full scale model has a built in log-normal rapping size distribution with a mmd of 6.0 μm and a standard deviation of 2.5 which may be used with this routine in the absence of other data.

Card 6 adjusts the ideal collection efficiencies to compensate for several non-ideal conditions. These conditions include gas sneakage around the collection regions of the precipitator and the velocity distribution associated with the inlet gas flow but exclude rapping. In addition there is an empirical correction to the migration velocities of particles with diameters less than 4.5 μm. This correction was derived from comparisons with measured migration velocities from full-scale precipitators in which the model predicted values were lower than these measured for small particle sizes. Card 6 has 2 starting points. The first is used if rapping reentrainment is to be calculated later. The second starting point is used if no rapping information is desired or if a rapping

correction has previously been calculated and the non-rapping conditions are being changed for the same rapping conditions. The program information on this card occupies 2 card sides. The printer lists the input data for this card. Following this, the particle diameter (μm) and adjusted efficiency (decimal) for each size band and the total adjusted efficiency are printed.

Card 7 computes the rapping adjustments to the efficiencies calculated by card 6. Before card 7 can be run, card 5 must have been run to establish a rapping puff size distribution. The information on this card occupies 1 side. No data are entered in this portion of the program. The printer lists the particle diameter (μm) and adjusted efficiency including rapping (decimal) for each size band followed by the total adjusted efficiency including rapping.

The purpose of card 8 is to allow the user to estimate the size distributions of the ESP effluent for the no-rap and rapping conditions. This routine prints the fraction of the particles by mass which occur in each size band, in order of increasing size, for inlet gas flow, adjusted no-rap outlet gas flow (card 6), and adjusted outlet gas flow including rapping (card 7). The fraction printed for the largest size band in the inlet distribution will appear to be larger than it should since all of the mass which lies outside the range of the 5 size bands is included in the largest band. In normal use, only a small portion of the mass will come from particles smaller than the 5 size bands. Most of the extra particles will be larger than the largest size band and will be collected in the ESP. However, this effect may also show up in the outlet fractions which are based on the inlet fraction.

SECTION 5

DEFINITIONS OF THE INPUT DATA

The following is a list of the variables required to operate the TI Programmable 59 version of the ESP model. These variables are listed by section of the program and are in the order in which they must be entered into the calculator. A definition is provided for each variable listed. Some of the variables are entered in British units and others are in SI units. The data which are in British units are converted to SI by the calculator for use in the program.

Card 1

D_{50} is the mass median diameter of a log-normal inlet particle size distribution and is in units of μm. The value of D_{50} must lie between 0.01 and 1,000 μm.

SIGMA is the geometric standard deviation of a log-normal inlet particle size distribution and is dimensionless. The value of SIGMA must be equal to or greater than 1.

E_1-E_6 are values of particle diameters corresponding to points on a curve of inlet mass cumulative percent versus particle diameter. The diameters must be entered in order from smallest to largest in units of μm. The smallest diameter can not be less than 0.01 μm and the largest diameter can not exceed 1,000 μm. These diameters are used to construct particle size intervals and a particle size histogram. The midpoints between successive particle diameters constitute five average particle diameters which are used in the program to characterize the different particle size bands. In constructing the particle diameters to be used in the calculations, it is recommended that greater resolution be built into the fine particle size range of 0.1-3.0 μm since the lower efficiencies are obtained in this size range.

Card 2

DL is the inlet particulate mass loading in units of grains/ft^3.

DD is the density of the particles in units of kg/m^3.

EPS is the dielectric constant of the particles for use in the particle charging calculations and is dimensionless. Values of EPS must be equal to or greater than 1. In most industrial applications, the flue gas is sufficiently humidified so that the particle surface becomes conductive and a value of EPS = 100 can be used to simulate a conductor.

US is the ionic mobility at standard temperature (273°K) and standard pressure (1 atm) for use in the particle charging calculations and is in units of $m^2/(V\text{-sec})$. This mobility is referred to as the "reduced mobility". Values to use for reduced ionic mobilities for flue gas compositions are not well-established at the present time. The reduced ionic mobility for air is in the range $1.2\text{-}2.1 \times 10^{-4}$ $m^2/(V\text{-sec})$. Reduced ionic mobilities for flue gas compositions have been reported that are considerably larger than those reported for air. These values cover the range of $2.2\text{-}5.4 \times 10^{-4}$ $m^2/(V\text{-sec})$. Some reported values of reduced ionic mobility for various gas compositions are given in Table 1. A value of 2.2×10^{-4} $m^2/(V\text{-sec})$ should provide a representative value to use in the model calculations.

TABLE 1

REDUCED EFFECTIVE NEGATIVE ION MOBILITIES FOR VARIOUS GAS COMPOSITIONS

Gas Composition (Volume Percent)					Reduced Effective Ion Mobility (cm^2/V-sec)
N_2	CO_2	O_2	SO_2	H_2O	
				100.0	0.67 ± 0.17[a]
		100.0			2.46 ± 0.06[b]
	100.0				1.08 ± 0.03[b]
			100.0		0.35[c]
	(Laboratory Air)				1.03[d]
	(Laboratory Air)				1.26 - 1.96[e]
79.4	14.7	4.6	0.2	0.6	5.39[f]
73.5	13.6	4.2	0.2	8.4	2.93[f]
65.9	12.2	3.8	0.2	17.8	2.23[f]
71.0	11.2	3.7	0.0	14.0	2.35[f]
75.7	11.6	3.2	0.0	9.4	3.02[f]
75.1	11.5	3.2	0.1	9.9	2.74[f]
78.5	10.9	3.6	0.0	7.0	3.36[f]
78.3	19.8	3.6	0.1	7.0	2.67[f]
77.9	10.8	3.6	0.3	7.0	2.70[f]
77.6	10.7	3.7	0.7	7.0	2.43[f]

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e. J. Bricard, M. Cabane, G. Modelaine, and D. Vigla, Aerosols and Atmospheric Chemistry. Edited by G. M. Hidy, New York, New York, 27 (1972).

f. H. W. Spencer, III, "Experimental Determination of the Effective Ion Mobility of Simulated Flue Gas." In Proceedings of 1975 IEEE-IAS Conference, September 28, 1975, Atlanta, Georgia.

PL — is the total electrical length of the precipitator in units of feet.

VGS — is the total gas volume flow rate in the precipitator and is in units of actual ft^3/min.

VGAS — is the gas velocity in the precipitator and is in units of ft/sec.

TEMP — is the gas temperature in the precipitator and is in units of °F.

P — is the gas pressure in the precipitator and is in units of atmospheres.

VIS — is the gas viscosity in the precipitator and is in units of kg/(m-sec). Table 2 gives values of viscosity for different temperatures and water contents for a gas composition whose components are those of air. This table provides values of viscosity which cover most cases found in practice although some extrapolation is necessary for those cases involving hot precipitators where temperatures are greater than 300°C.

ETAO — is the estimated overall mass collection efficiency in units of percent. ETAO is used as a starting point in calculating the amount of particulate collected in each incremental length of the precipitator.

TABLE 2. VALUES OF VISCOSITY FOR AIR AT VARIOUS TEMPERATURES AND WATER CONTENTS*

	Percent H_2O										
°C	0	1	2	3	4	5	6	7	8	9	10
10	1.767	1.758	1.748	1.739	1.730	1.721	1.712	1.702	1.693	1.684	1.675
20	1.810	1.801	1.792	1.783	1.774	1.765	1.755	1.746	1.737	1.728	1.719
30	1.854	1.844	1.835	1.826	1.817	1.808	1.799	1.790	1.780	1.771	1.762
40	1.900	1.887	1.878	1.869	1.860	1.850	1.841	1.832	1.823	1.814	1.805
50	1.938	1.929	1.920	1.911	1.902	1.892	1.883	1.874	1.865	1.856	1.847
60	1.979	1.970	1.961	1.952	1.943	1.934	1.925	1.916	1.907	1.898	1.888
70	2.020	2.011	2.002	1.993	1.984	1.975	1.966	1.957	1.948	1.939	1.930
80	2.059	2.050	2.042	2.033	2.024	2.015	2.006	1.997	1.988	1.979	1.970
90	2.099	2.090	2.081	2.072	2.063	2.054	2.046	2.037	2.028	2.019	2.010
100	2.137	2.129	2.120	2.111	2.102	2.093	2.085	2.076	2.067	2.058	2.049
110	2.175	2.167	2.158	2.149	2.140	2.132	2.123	2.114	2.105	2.097	2.088
120	2.213	2.204	2.195	2.189	2.178	2.169	2.161	2.152	2.143	2.135	2.126
130	2.250	2.241	2.232	2.224	2.215	2.207	2.198	2.189	2.181	2.172	2.164
140	2.286	2.277	2.269	2.260	2.252	2.243	2.235	2.226	2.218	2.209	2.201
150	2.321	2.313	2.304	2.296	2.288	2.279	2.271	2.262	2.254	2.245	2.237
160	2.356	2.348	2.339	2.331	2.323	2.315	2.306	2.298	2.289	2.281	2.273
170	2.390	2.382	2.374	2.366	2.358	2.349	2.341	2.333	2.325	2.316	2.308
180	2.424	2.416	2.408	2.400	2.392	2.383	2.375	2.367	2.359	2.351	2.343
190	2.457	2.449	2.441	2.433	2.425	2.417	2.409	2.401	2.393	2.385	2.377
200	2.489	2.482	2.474	2.466	2.458	2.450	2.442	2.434	2.426	2.418	2.410
210	2.521	2.513	2.506	2.498	2.490	2.482	2.475	2.467	2.459	2.451	2.443
220	2.552	2.545	2.537	2.530	2.522	2.514	2.507	2.499	2.491	2.483	2.476
230	2.583	2.575	2.568	2.560	2.553	2.545	2.538	2.530	2.523	2.515	2.507
240	2.613	2.606	2.598	2.591	2.583	2.576	2.569	2.561	2.554	2.546	2.539
250	2.642	2.635	2.628	2.621	2.613	2.606	2.599	2.592	2.584	2.577	2.570
260	2.671	2.664	2.657	2.650	2.643	2.636	2.628	2.621	2.614	2.607	2.600
270	2.699	2.692	2.685	2.678	2.671	2.664	2.657	2.650	2.643	2.636	2.629
280	2.727	2.720	2.713	2.706	2.700	2.693	2.686	2.679	2.672	2.665	2.658
290	2.754	2.747	2.740	2.734	2.727	2.720	2.714	2.707	2.700	2.694	2.687
300	2.780	2.773	2.767	2.761	2.754	2.748	2.741	2.734	2.728	2.721	2.715

X 10^{-5} kg/(m-sec)

*Calculations according to:
C.R. Wilke. A Viscosity Equation for Gas Mixtures. J. Chem. Phy., 18(4):517-519 (April, 1950).

LINC — is the incremental precipitator length used for efficiency calculations and is in units of feet. The same value of LINC is used throughout the precipitator. The product of LINC and LSECT for each electrical section must equal the total length of that section.

Card 3

LSECT — is the number of increments of length LINC to be used in the electrical section being examined. (Section III and Section IV are repeated for each electrical section of the precipitator.) If LSECT = 0, the program will terminate the initial efficiency calculation by printing the particle size band diameters in μm and the ideal particle collection efficiencies for each size band expressed as a decimal.

A — is the total collection plate area for the electrical section being examined and is in units of square feet.

VOS — is the applied voltage in the electrical section being examined and is in units of volts.

TC — is the total current in the electrical section being examined and is in units of amperes.

B — is the wire-to-plate spacing in the electrical section being examined and is in units of inches.

Card 4 — No input data.

Card 5

D_{50} is the mass median diameter of a log-normal rapping puff size distribution and is in units of μm. The value of D_{50} must lie between 0.01 and 1,000 μm.

SIGMA is the geometric standard deviation of the log-normal rapping puff size distribution and is dimensionless. SIGMA must have a value equal to or greater than 1.

E_1-E_6 are particle diameters corresponding to the endpoints of the same five size bands constructed in Section I. These values must be the same as those in Section I.

Card 6

PL is the total electrical length of the precipitator in units of feet. This is the same value used in Section II.

PLLS is the total electrical length of the last electrical section of the precipitator in units of feet.

P is the gas pressure in the precipitator and is in units of atmospheres. This is the same value used in Section II.

TEMP is the gas temperature in the precipitator and is in units of °F. This is the same value used in Section II.

NTEMP is an indicator which can have the values of 1 and 2. The mass reentrained due to rapping will differ for cold-side and hot-side precipitators. If NTEMP = 1, the mass reentrained due to rapping is estimated based on an equation for cold-side precipitators. If NTEMP = 2, the mass reentrained due to rapping is estimated based on an equation for hot-side precipitators.

SNUCK — is the fraction of gas flow which bypasses the electrified regions of the precipitator and/or the fraction of the mass collected in the precipitator which is reentrained due to factors other than rapping. SNUCK must have a value in the range 0.0 to 1.0.

ZIGGY — is the normalized standard deviation for the inlet velocity distribution of the gas flow. ZIGGY must be equal to or greater than 0.0.

ZNUMS — is the number of baffled stages in the precipitator. The value of ZNUMS must be an integer.

ATOTAL — is the total collection plate area for the entire precipitator and is in units of square feet.

Card 7 — No input data.

Card 8 — No input data.

SECTION 6

PROGRAM OPERATION PROCEDURE

In order to operate the ESP model on the Programmable 59 calculator, it is necessary to execute the following steps exactly as they are given. The first step initializes the calculator so that the program may be run. The second step lists the procedure required to run the ideal efficiency calculation. Non-ideal corrections with rapping are given in step 3 and corrections without rapping in step 4. Step 5 lists a shortened procedure for changing the non-ideal conditions. A change in ESP operating conditions necessitates beginning again at step 1.

1. Initializing the calculator

31

17

44

37

2N OP 04

7

2N OP 17

2N CMS

RST

If the program has been run with one set of ESP operating conditions and it is desired to run another set or if an error has been made and it is necessary to start over, the calculator may be reinitialized with the following two steps:

2N CMS

RST

2. Ideal calculation

1

INV 2N Write (insert Card 1)

D_{50} A

SIGMA R/S (wait for display)

E_1 R/S

E_2 R/S

E_3 R/S

E_4 R/S

E_5 R/S

E_6 R/S (wait for NEXT)

```
1
INV 2N Write        (insert Card 2 side 1)
2
INV 2N Write        (insert Card 2 side 2)

A                   (wait for display:  8.85-12)
DL          R/S
DD          R/S
EPS         R/S
US          R/S
PL          R/S
VGS         R/S
VGAS        R/S
TEMP        R/S
P           R/S
VIS         R/S
ETAO        R/S
LINC        R/S     (wait for NEXT)
1
INV 2N Write        (insert Card 3)

A
LSECT       R/S
A           R/S
VOS         R/S
TC          R/S
B           R/S     (wait for NEXT)
```

1

INV 2N Write (insert Card 4 side 1)

2

INV 2N Write (insert Card 4 side 2)

A (wait for NEXT)

Repeat Card 3 and Card 4 for each subsequent electrical section of the precipitator. Side 2 of Card 4 need not be reentered as only side 1 is written over by Card 3. After all sections of the precipitator have been entered into the program and Card 4 has been completed for the final section, enter Card 3 again using LSECT = 0. This will cause the ideal collection efficiencies in each size band to be calculated, printed, and stored for later use. Size band diameters and the overall efficiency are also printed.

3. Non-ideal effects including rapping

1

INV 2N Write (insert Card 1 as Card 5)

rapping D_{50} A

rapping SIGMA R/S (wait for display)

E_1 R/S

E_2 R/S

E_3 R/S

E_4 R/S

E_5 R/S

E_6 R/S (wait for NEXT)

```
1
INV 2N Write      (insert Card 6 side 1)
2
INV 2N Write      (insert Card 6 side 2)

A                 (wait for display:  2.6  01)
PL        R/S
PLLS      R/S
PS        R/S
TEMP      R/S
NTEMP     R/S
SNUCK     R/S
ZIGGY     R/S
ZNUMS     R/S
ATOTAL    R/S     (wait for NEXT)
```

The line printer will print the size bands, collection efficiencies corrected for non-ideal effects not including rapping for each size band, and the overall no-rap corrected efficiency.

```
1
INV 2N Write      (insert Card 7)

A                 (wait for NEXT)
```

The line printer will print the size bands, collection efficiencies corrected for non-ideal effects including rapping for each size band, and the overall corrected efficiency.

1

INV 2N Write (insert Card 8)

A (wait for NEXT)

The line printer will print the fraction by mass of the inlet particle size distribution which occurs in each size band. The largest size band will be increased by the fraction of mass which occurs in the range 0.01 to 1000 μm but which falls outside the size bands as defined in Card 1. The line printer will then print the fraction by mass in each size band of the outlet size distribution corrected for non-ideal conditions not including rapping. The same data for non-ideal conditions including rapping is then printed. From this data it is possible to estimate the outlet size distribution. If this data is not desired, Card 8 may be omitted.

4. Non-ideal effects excluding rapping

(omit Card 5)

1

INV 2N Write (insert Card 6 side 1)

2

INV 2N Write (insert Card 6 side 2)

SNUCK B

ZIGGY R/S

ZNUMS R/S

ATOTAL R/S (wait for NEXT)

The line printer will print the size bands, collection efficiencies corrected for non-ideal effects not including rapping for each size band, and the overall no-rap corrected efficiency.

(omit Card 7)

1

INV 2N Write (insert Card 8)

A (wait for NEXT)

The line printer will print the fraction by mass in each size band of the inlet particle size distribution and then for the corrected no-rap outlet particle size distribution. The printer will then attempt to do the same for the non-ideal corrections including rapping. However, since Card 7 was omitted, the numbers printed will not have any bearing on the outlet particle size distribution.

5. Changing non-ideal conditions

The ideal efficiency calculations are not destroyed by the application of the non-ideal corrections. Therefore, it is not necessary to repeat steps 1 and 2 of this procedure in order to calculate the corrections for a different set of non-ideal conditions. To calculate the corrections for the case where a change in rapping data is desired, repeat the procedure listed under step 3. However, if step 3 has been performed and the desired changes in the non-ideal conditions occur in the variables SNUCK, ZIGGY, or ZNUMS and not in the data pertaining to the rapping conditions, it is simpler to use the following procedure:

(omit Card 5)

1

INV 2N Write (insert Card 6 side 1)

SNUCK B

ZIGGY R/S

ZNUMS R/S

ATOTAL R/S (wait for NEXT)

The printer prints the new non-ideal no-rap corrections.

1

INV 2N Write (insert Card 7)

A (wait for NEXT)

The printer prints the new non-ideal corrections with rapping.

1

INV 2N Write (insert Card 8)

A (wait for NEXT)

The printer prints the new fractions by mass in each size band for the inlet and the outlet with the new corrections with and without rapping.

REFERENCES

1. Gooch, J. P., J. R. McDonald, and S. Oglesby, Jr. A Mathematical Model of Electrostatic Precipitation. EPA-650/2-75-037, U.S. Environmental Protection Agency, Raleigh Durham, North Carolina, 1975.

2. McDonald, J. R. A Mathematical Model of Electrostatic Precipitation (Revision 1): Volume I. Modeling and Programming, EPA-600/7-78-111a, NTIS No. PB284-614, June 1978.

3. McDonald, J. R. A Mathematical Model of Electrostatic Precipitation (Revision 1): Volume II. User Manual, EPA-600/7-78-111b, NTIS No. PB284-615, June 1978.

APPENDIX 1

FLOW CHARTS

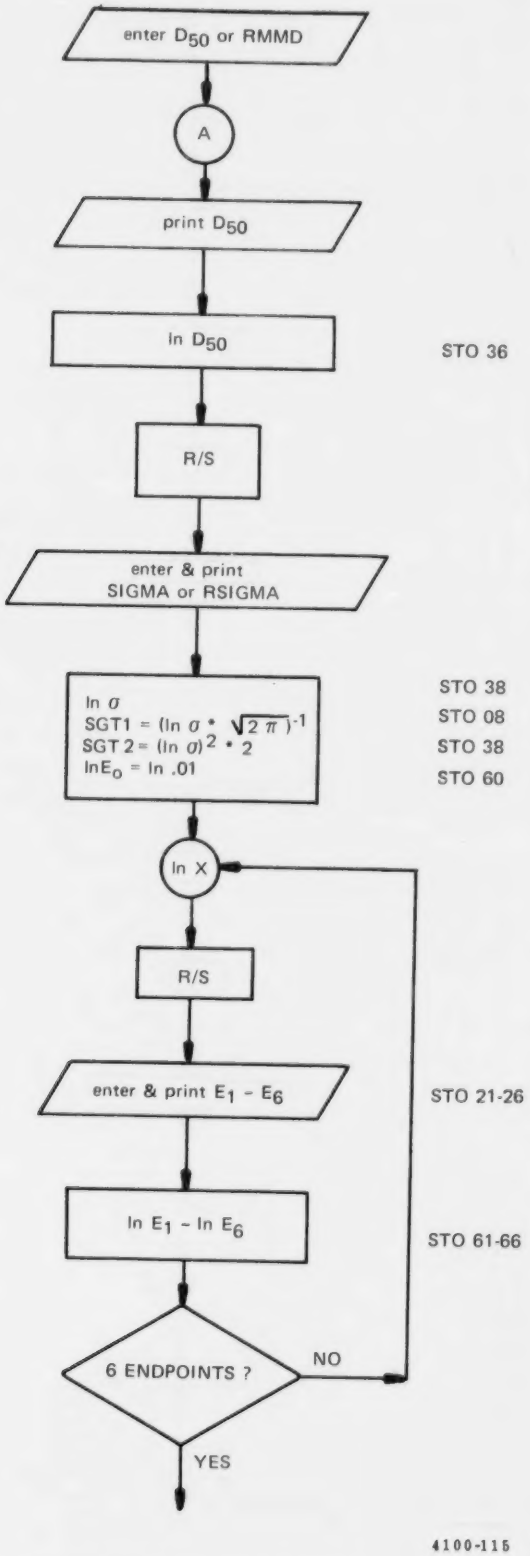


Figure 1. Flowchart for card 1 and 5 (sheet 1 of 3).

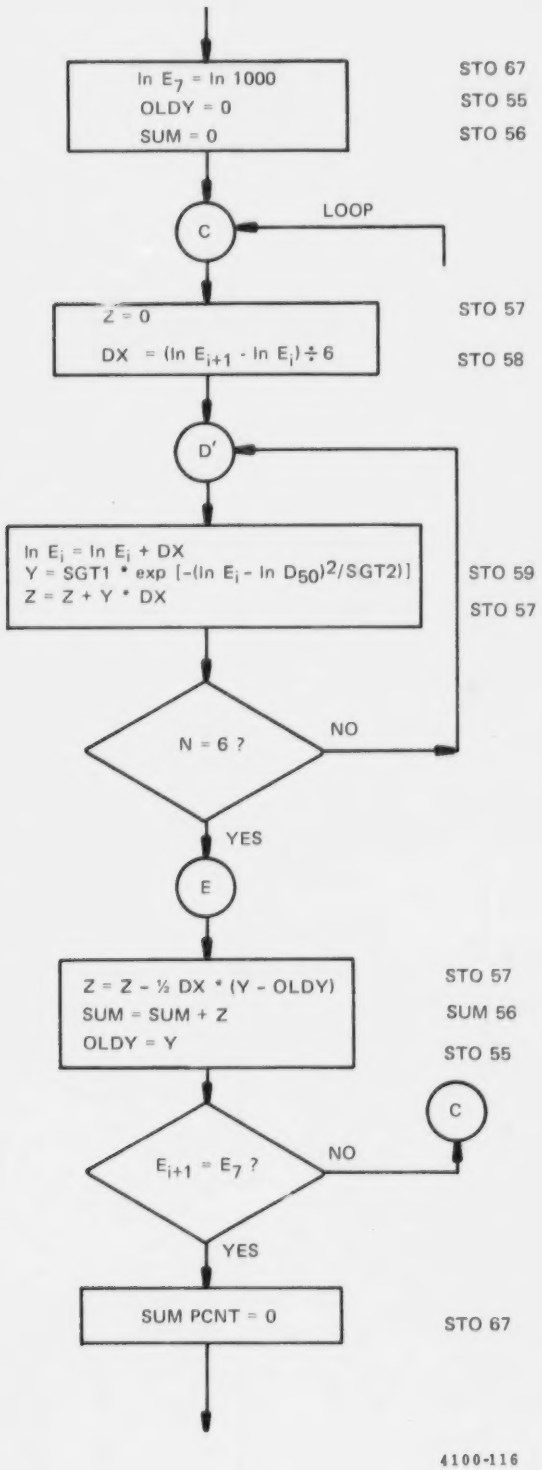


Figure 1. Flowchart for card 1 and 5 (sheet 2 of 3).

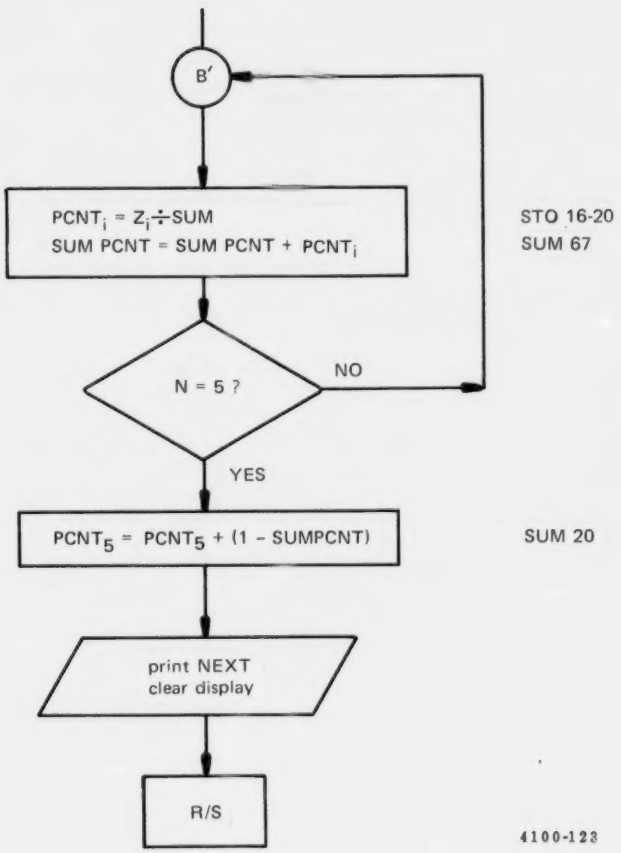


Figure 1. Flowchart for card 1 and 5 (sheet 3 of 3).

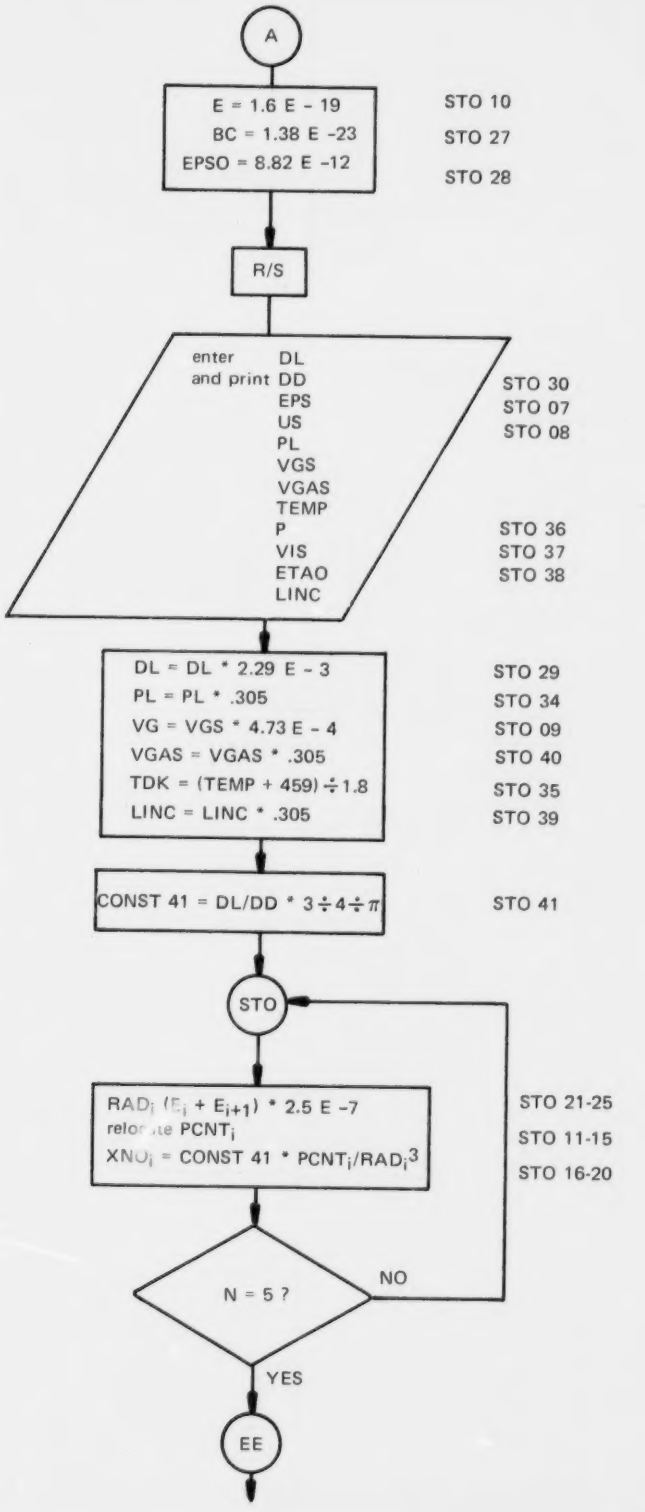


Figure 2. Flowchart for card 2 (sheet 1 of 2).

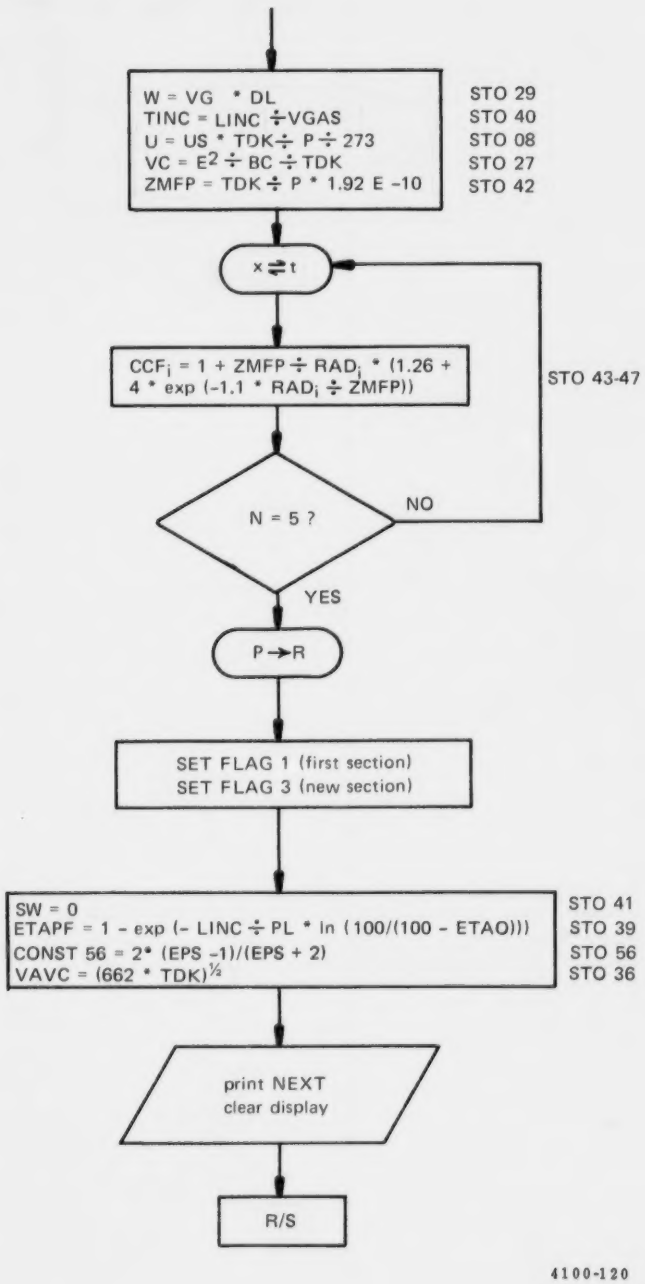

W = VG * DL
TINC = LINC ÷ VGAS
U = US * TDK ÷ P ÷ 273
VC = E2 ÷ BC ÷ TDK
ZMFP = TDK ÷ P * 1.92 E -10
STO 29
STO 40
STO 08
STO 27
STO 42
x ⇄ t
CCFi = 1 + ZMFP ÷ RADi * (1.26 + 4 * exp (-1.1 * RADi ÷ ZMFP))
STO 43-47
N = 5 ?
NO
YES
P → R
SET FLAG 1 (first section)
SET FLAG 3 (new section)
SW = 0
ETAPF = 1 - exp (- LINC ÷ PL * ln (100/(100 - ETAO)))
CONST 56 = 2* (EPS -1)/(EPS + 2)
VAVC = (662 * TDK)½
STO 41
STO 39
STO 56
STO 36
print NEXT
clear display
R/S
4100-120

Figure 2. Flowchart for card 2 (sheet 2 of 2).

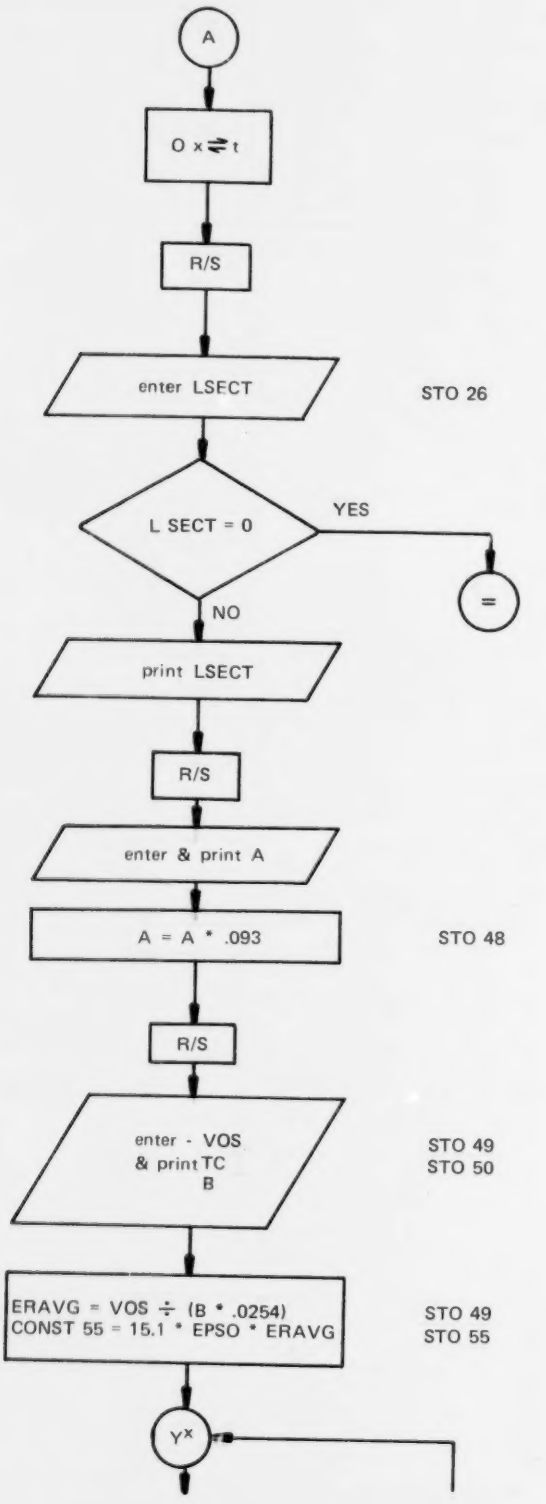


Figure 3. Flowchart for card 3 (sheet 1 of 3).

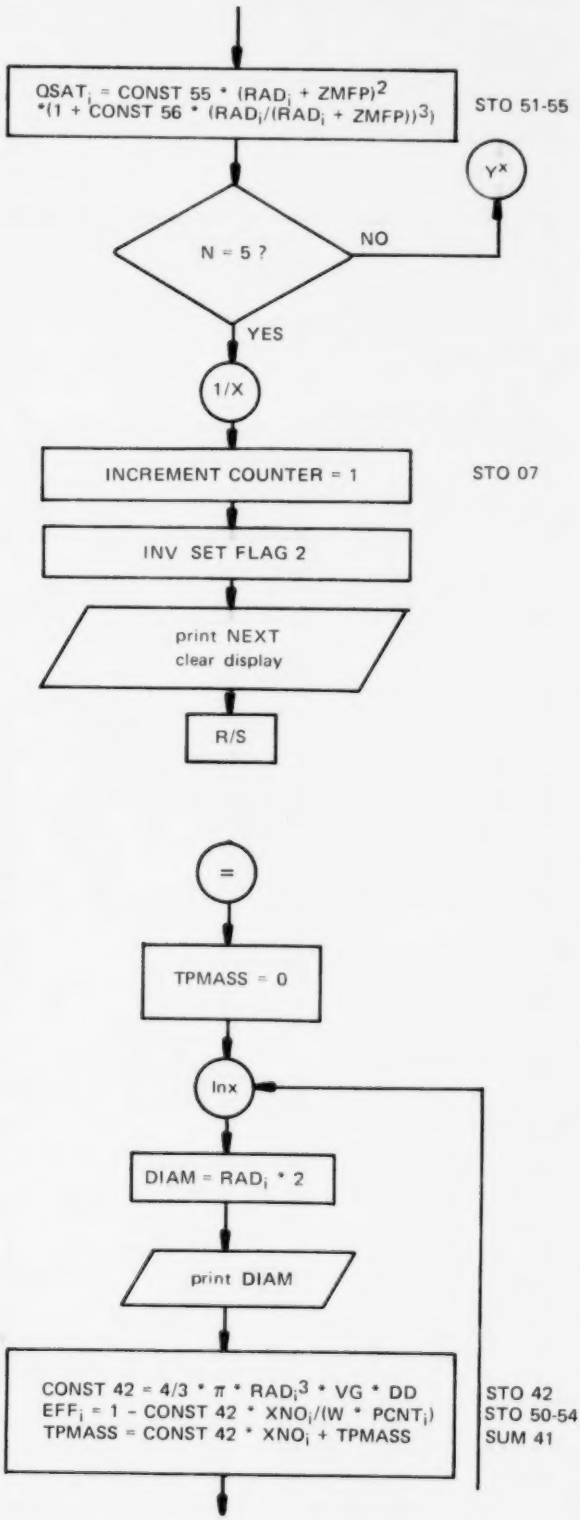


Figure 3. Flowchart for card 3 (sheet 2 of 3).

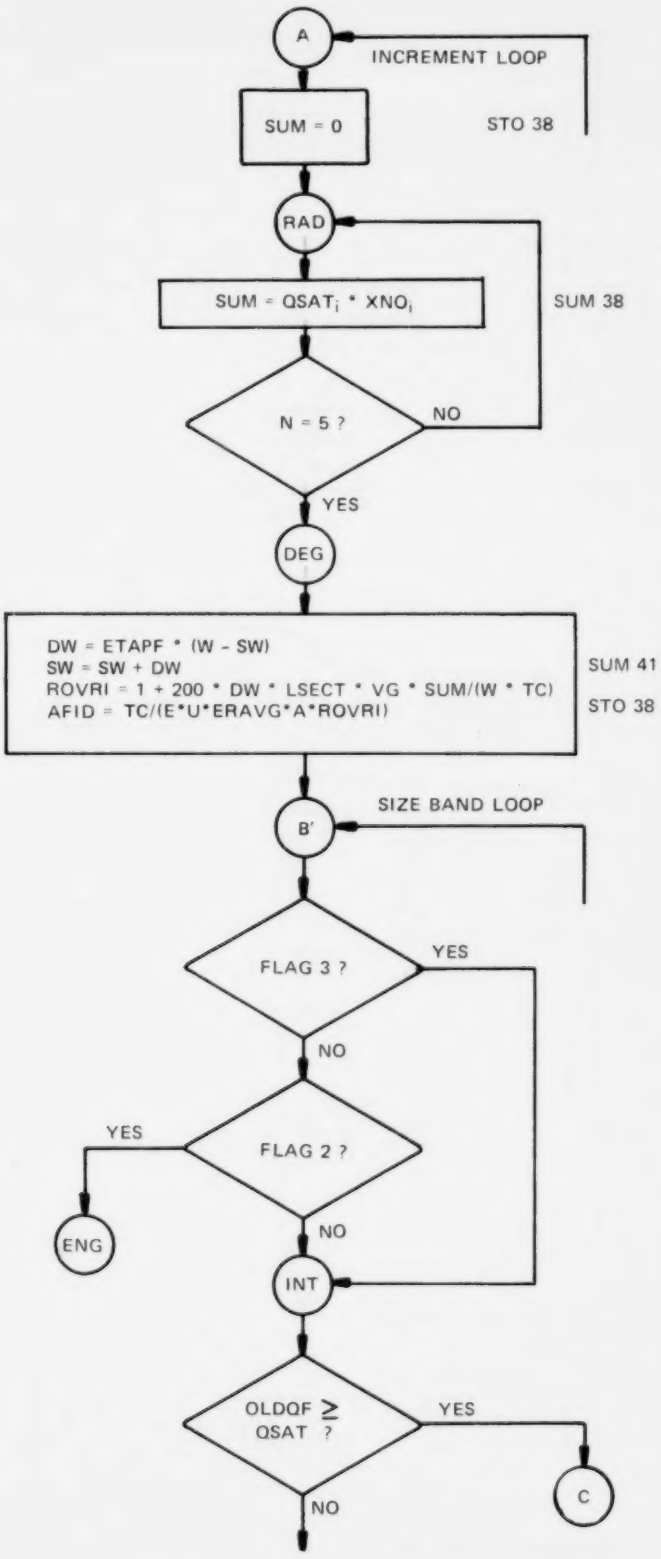


Figure 4. Flowchart for card 4 (sheet 1 of 4).

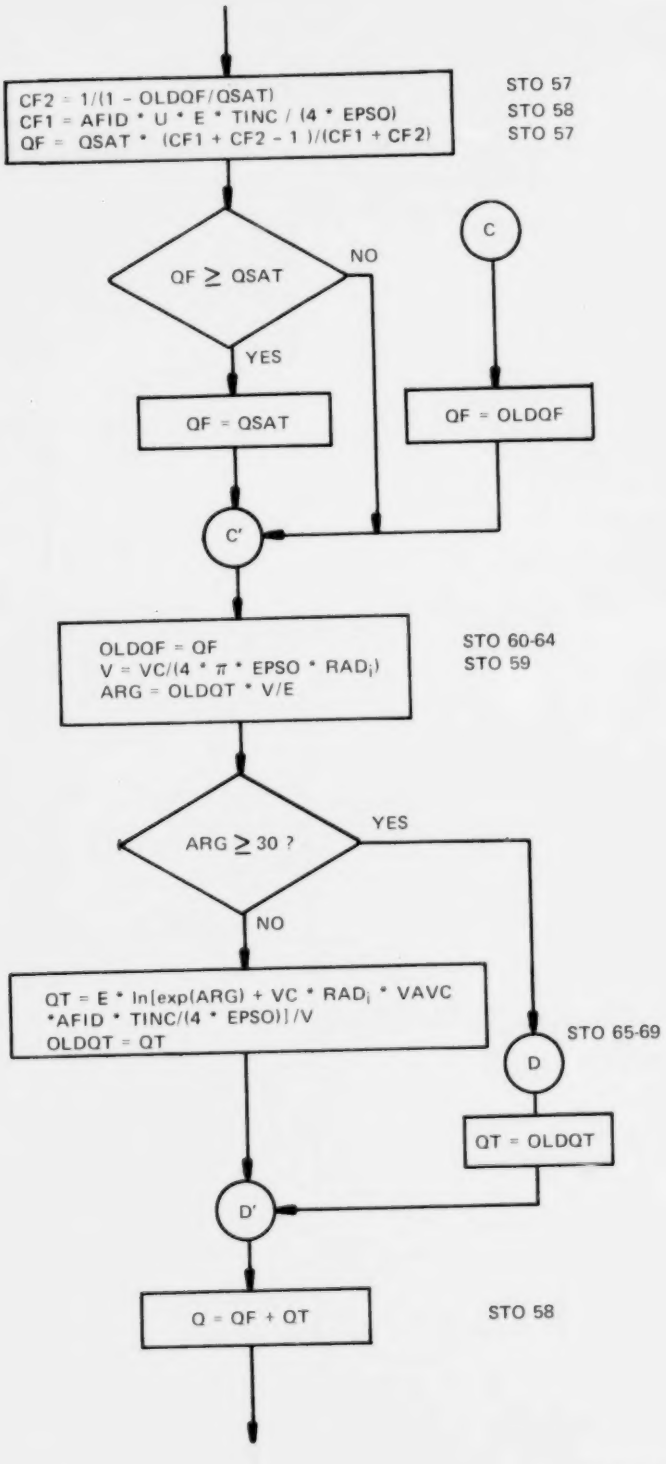
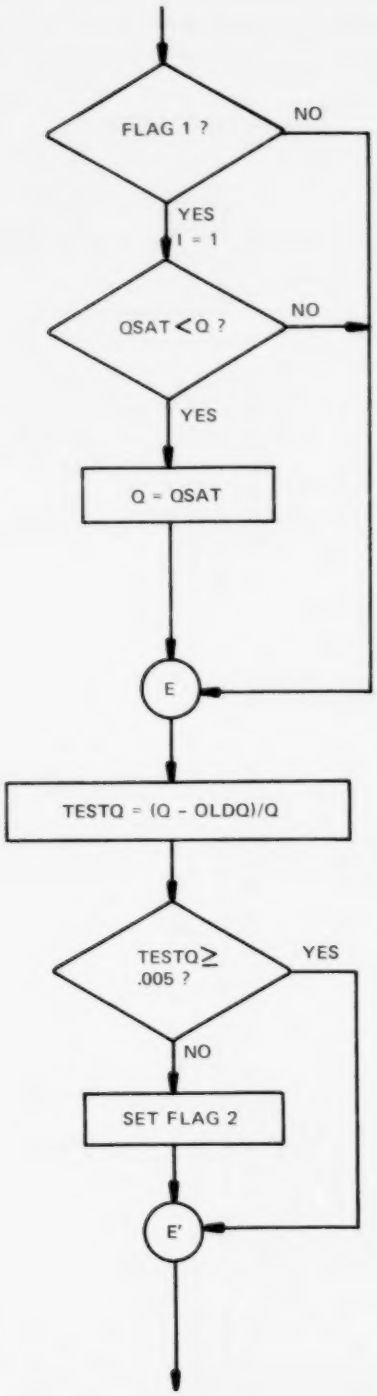


Figure 4. Flowchart for card 4 (sheet 2 of 4).



4100-113

Figure 4. Flowchart for card 4 (sheet 3 of 4).

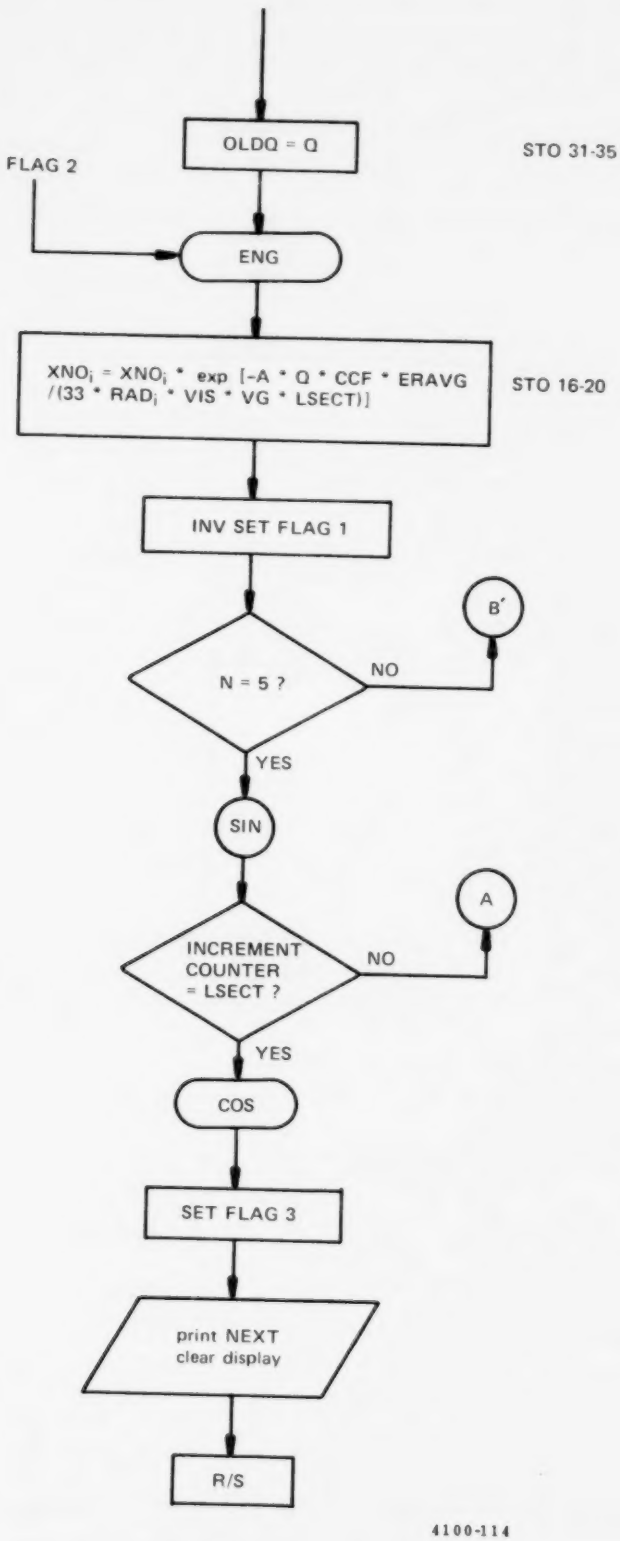


Figure 4. Flowchart for card 4 (sheet 4 of 4).

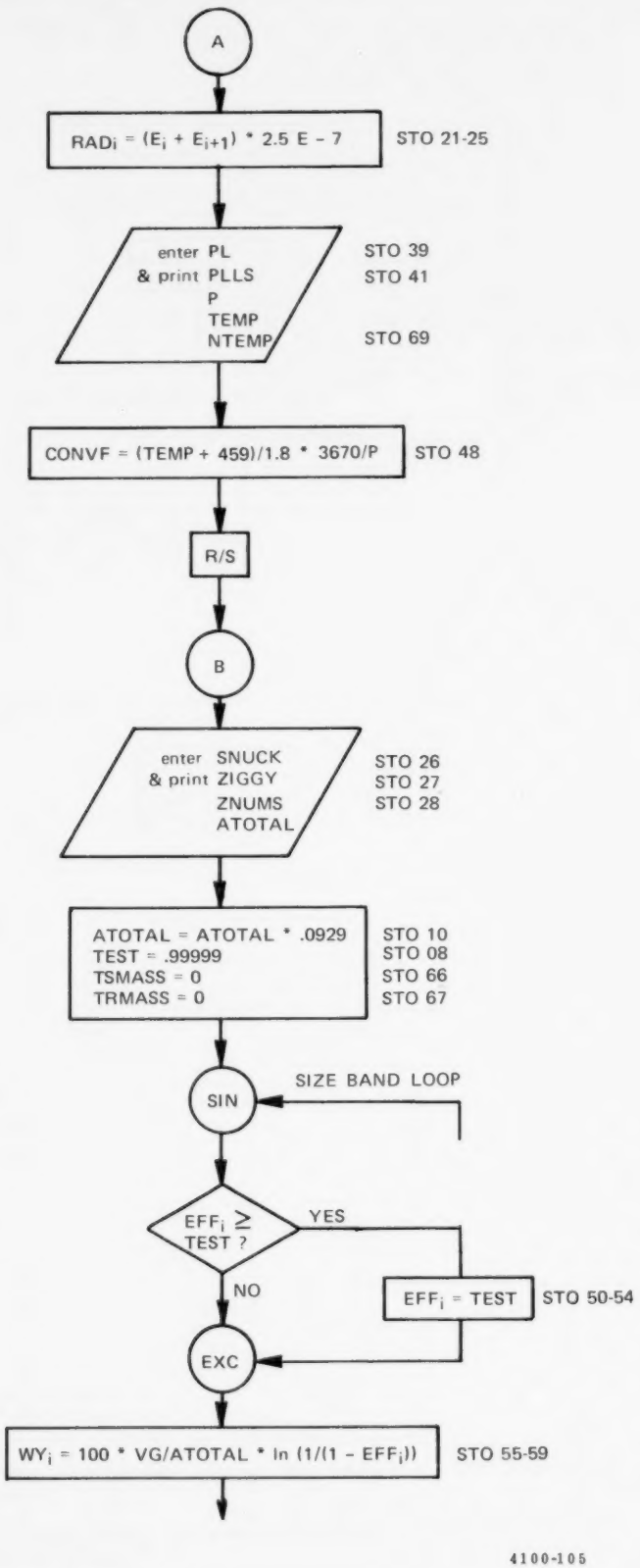


Figure 5. Flowchart for card 6 (sheet 1 of 3).

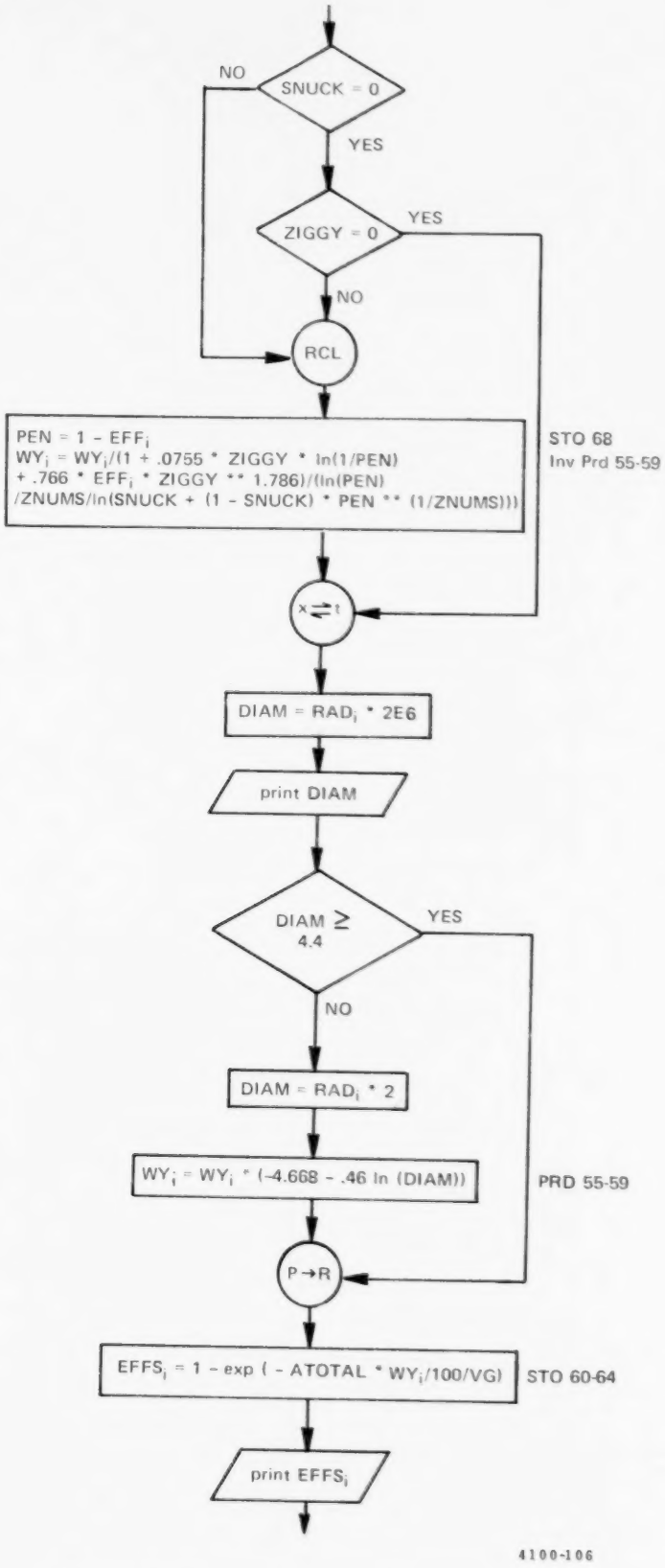


Figure 5. Flowchart for card 6 (sheet 2 of 3).

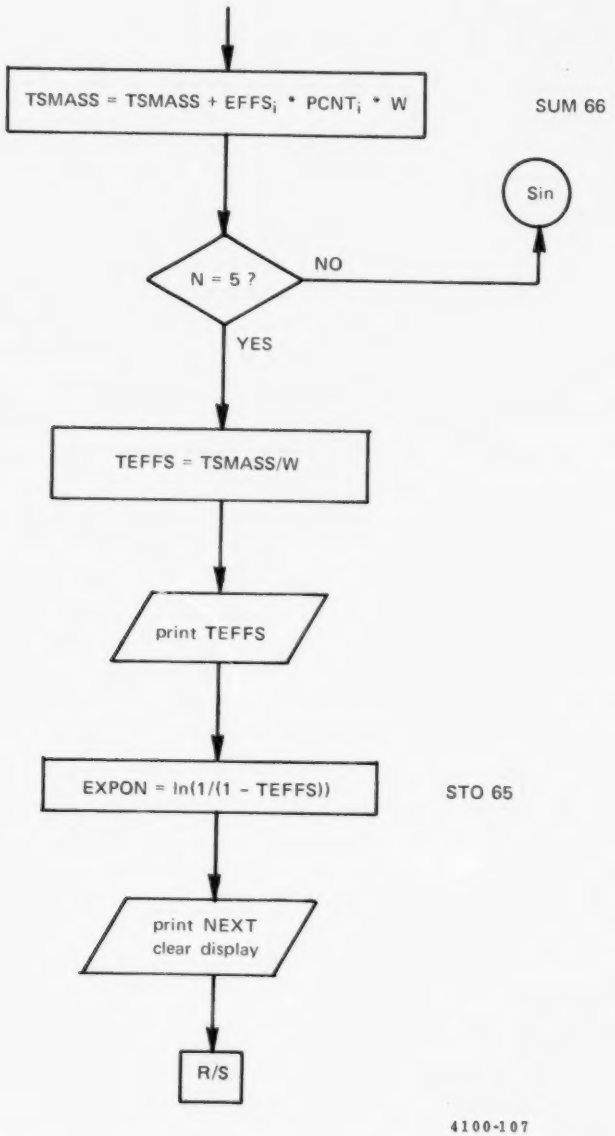


Figure 5. Flowchart for card 6 (sheet 3 of 3).

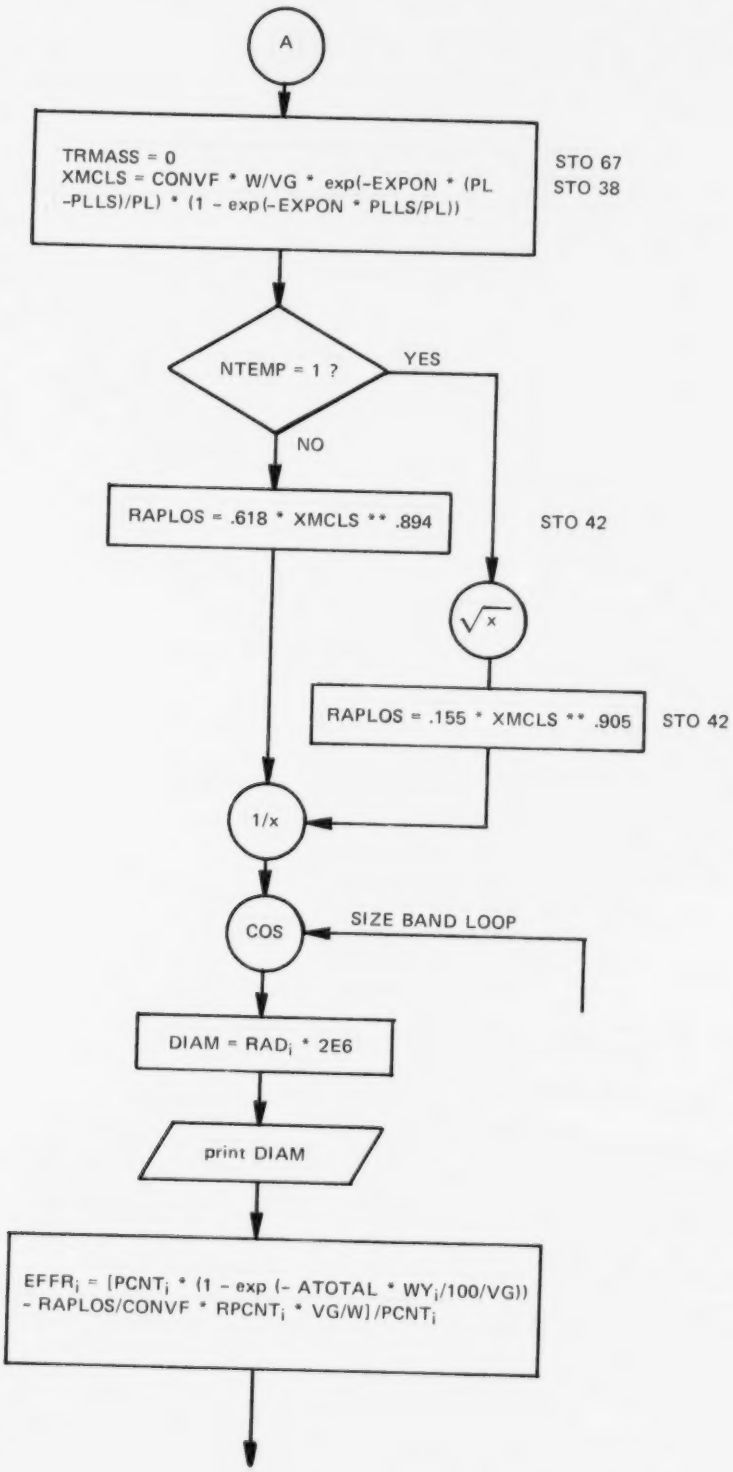

A
TRMASS = 0
XMCLS = CONVF * W/VG * exp(-EXPON * (PL -PLLS)/PL) * (1 - exp(-EXPON * PLLS/PL))
STO 67
STO 38
NTEMP = 1 ?
YES
NO
RAPLOS = .618 * XMCLS ** .894
STO 42
√x
RAPLOS = .155 * XMCLS ** .905
STO 42
1/x
COS
SIZE BAND LOOP
DIAM = RADi * 2E6
print DIAM
EFFRi = [PCNTi * (1 - exp (- ATOTAL * WYi/100/VG)) - RAPLOS/CONVF * RPCNTi * VG/W]/PCNTi
4100-117

Figure 6. Flowchart for card 7 (sheet 1 of 2).

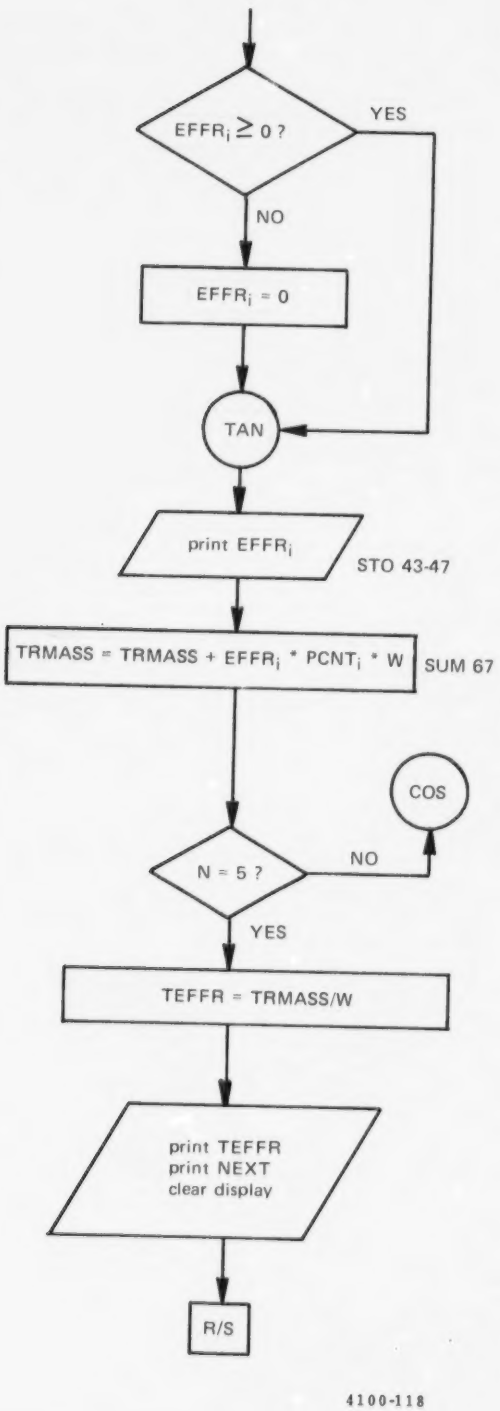


Figure 6. Flowchart for card 7 (sheet 2 of 2).

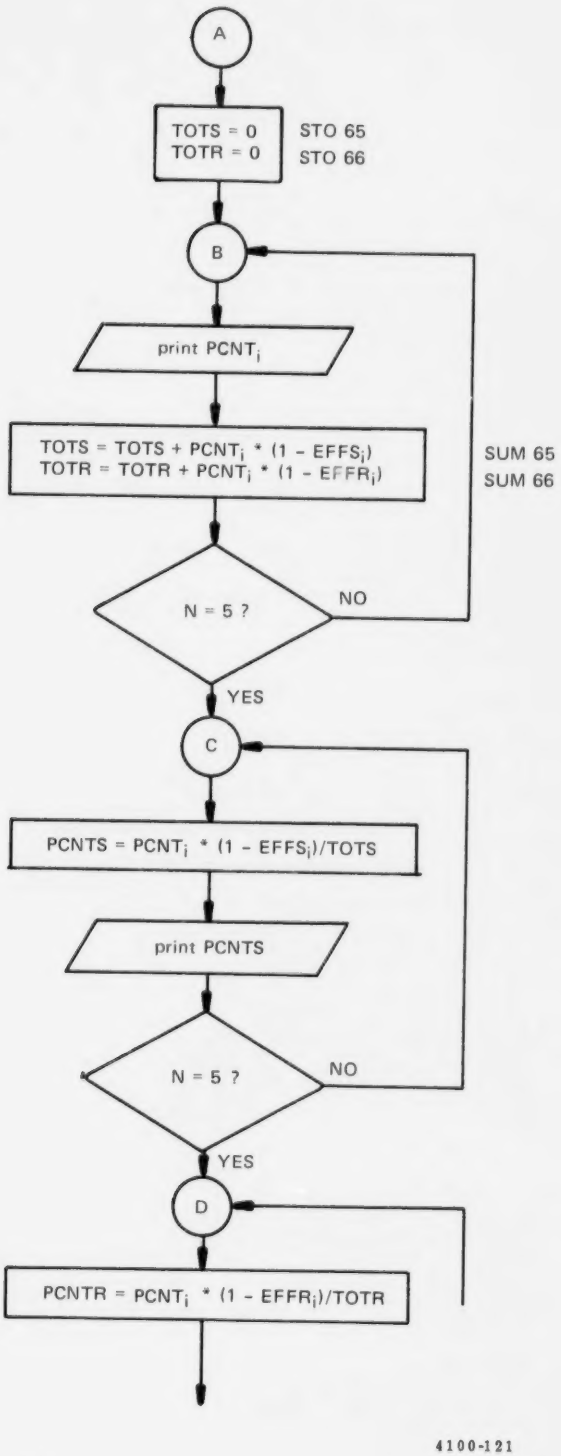


Figure 7. Flowchart for card 8 (sheet 1 of 2).

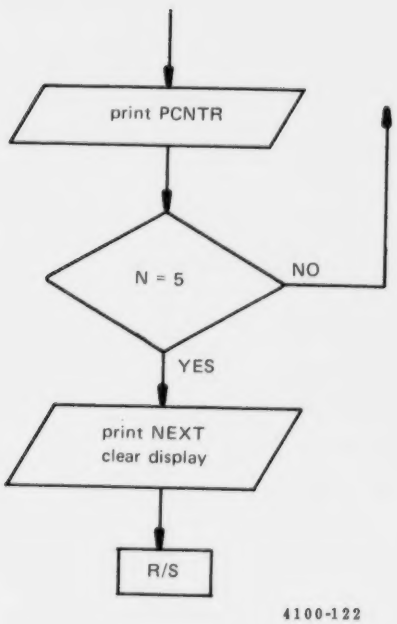


Figure 7. Flowchart for card 8 (sheet 2 of 2).

APPENDIX 2

DEFINITIONS OF THE VARIABLE NAMES USED IN THE FLOWCHARTS OF APPENDIX 1

D50 - Specified mass median diameter of the inlet particle size distribution based on a log-normal distribution (μm)

RMMD - Specified mass median diameter of the rapping puff particle size distribution based on a log-normal distribution (μm)

SIGMA - Specified geometric standard deviation of the inlet particle size distribution based on a log-normal distribution

RSIGMA - Specified geometric standard deviation of the rapping puff particle size distribution based on a log-normal distribution

SGT1 - Value of the quantity $[1/(2\pi*\ln\sigma)]$ used to calculate Y

SGT2 - Value of the quantity $[2*(\ln\sigma)^2]$ used to calculate Y

E_i - Particle diameters specified for use in constructing the log-normal distribution histogram (μm)

OLDY - Final value of Y in the previous size band used to correct Z for end effects in the integration procedure

SUM - Total fraction by mass contained in the histogram specified by the user

Z - Cumulative integral resulting from the integration of the log-normal distribution function over a specified particle size band

DX - Step size taken for the Trapezoidal Rule integration of the log-normal distribution function over the different particle size bands

Y - Value of the log-normal distribution function at different values of the independent variable for use in integrating the function over the specified size bands

$PCNT_i$ - Fraction by mass in the inlet particle size distribution of the different size bands (decimal)

SUMPCNT - Σ $PCNT_i$ used to include the mass from particles whose sizes lie between 0.01 and 1000 μm but lie outside the five size bands.

E - Elementary charge unit (coul)

BC - Boltzmann's constant (J/°K)

EPSO - Permittivity of free space ($coul^2/nt\text{-}m^2$)

DL - Inlet mass loading (grains/ft^3 and kg/m^3)

DD - Mass density of the particles (kg/m^3)

EPS - Relative dielectric constant of the particles

US - Ion mobility at standard temperature and pressure (reduced ion mobility)

PL - Total electrical length of the precipitator (ft and m)

VGS - Gas volume flow rate (ft^3/min)

VGAS - Gas velocity (ft/sec and m/sec)

TEMP - Gas temperature (°F)

P - Gas pressure (atm)

VIS - Gas viscosity (kg/m-sec)

ETAO - Estimated or design overall mass collection efficiency (%)

LINC - Length of the increments taken in each linear electrical section (ft and m)

VG - Gas volume flow rate (m^3/sec)

TDK - Temperature of the gas (°K)

CONST41 - Value of the quantity [DL/DD*3/4/π] used in the equation for XNO_i

RAD_i - Radii of the different particle sizes (m)

XNO_i - Number of particles per cubic meter of gas in each size band at the start of each increment ($\#/m^3$)

W - Total weight of particles per second at the inlet (kg/sec)

TINC - Time interval for the gas to travel one increment (sec)

U - Ion mobility adjusted for temperature and pressure (m^2/V-sec)

VC - Value of the quantity [e^2/kT] found in the charging equations (coul/V)

ZMFP - Ionic mean free path (m)

CCF_i - Cunningham correction factor for the different particle sizes

SW - Cumulative sum of estimated amount of material removed per second in successive length increments (kg/sec)

ETAPF - Overall mass collection fraction per increment based on the estimated efficiency

CONST56 - Value of the quantity [2*(EPS-1)/(EPS+2)] used in the equation for $QSAT_i$

VAVC - Root mean square velocity of the ions (m/sec)

LSECT - Number of length increments in a particular linear electrical section

A - Collection plate area of a particular linear electrical section (ft^2 and m^2)

VOS - Applied voltage in a particular linear electrical section (V)

TC - Total current in a particular linear electrical section (A)

B - Wire-to-plate spacing in a particular linear electrical section (in. and m)

ERAVG - Average electrical field used for particle charging (V/m)

CONST55 - Value of the quantity [15.1*EPSO*ERAVG] used in the equation for $QSAT_i$

$QSAT_i$ - Saturation charge for the different particle sizes (coul)

TPMASS - Total penetration mass per second in the ideal case (kg/sec)

DIAM - Diameters of the different particle sizes (μm and m)

CONST42 - Value of the quantity [$4\pi/3*RAD_i^3*VG*DD$] used in the equations for TPMASS and EFF_i

EFF_i - Ideal particle collection efficiency in each size band

EFFT - Total ideal particle collection efficiency

SUM - Total particulate charge density in a given increment based on saturation charges ($coul/m^3$)

DW - Amount of material removed per increment on a total weight basis (kg)

ROVRI - Ratio of the total space charge density to the ionic space charge density

AFID - Average reduced free ion density for particle charging in a particular length increment ($\#/m^3$)

$OLDQF_i$ - Value of field charge on the different particle sizes at the end of a given increment (coul)

CF1 - Value of the quantity $[(N_0be/4\varepsilon_0)(t_f-t_i)]$ found in the equation for QF

CF2 - Value of the quantity $[1/(1-q_i/q_s)]$ found in the equation for QF

QF - Charge on a given particle size in a given increment due to field charging (coul)

V - Value of the quantity [VC/(4π*EPSO*RAD_i)] used in the equation for QT

ARG - Value of the quantity [OLDQT*V/E] used in the equation for QT

QT - Charge on a given particle size in a given increment due to diffusion charging (coul)

$OLDQT_i$ - Value of diffusion charge on the different particle sizes at the end of the prior increment (coul)

Q(K) - Total charge on each particle size at the end of a particular increment (coul)

$OLDQ_i$ - Total charge on the different particle sizes in the increment prior to the one under consideration (coul)

TESTQ - Change in the total charge from the prior increment to the one under consideration

PLLS - Total electrical length of the last electrical section of the precipitator (ft)

NTEMP - Indicator which specifies whether the precipitator is cold or hot side

CONVF - Conversion factor which converts kg/ACM to mg/DSCM

SNUCK - Fraction of gas sneakage and/or particle reentrainment without rapping

ZIGGY - Normalized standard deviation of the gas velocity distribution

ZNUMS - Number of stages over which gas sneakage and/or particle reentrainment without rapping occur

ATOTAL - Total collection plate area of the precipitator (ft^2 and m^2)

TEST - Maximum allowed value of efficiency for the non-ideal corrections

TSMASS - Total particulate mass collected per second in the precipitator after corrections for non-ideal effects excluding rapping (kg/sec)

TRMASS - Total particulate mass collected per second in the precipitator after corrections for non-ideal effects including rapping (kg/sec)

WY_i - Adjusted migration velocity for a given particle size under no-rap conditions (cm/sec)

PEN - Ideal particle penetration in each size band (fraction)

$EFFS_i$ - Adjusted particle collection efficiency in each size band for the no-rap case

TEFFS - Total adjusted particle collection efficiency for the no-rap case

EXPON - Value of the quantity [ln(1/(1-TEFFS))] for use in the equation for XMCLS

XMCLS - Mass collected in the last section of the precipitator from either ideal or adjusted no-rap calculations (mg/DSCM)

RAPLOS - Mass contained in the outlet emissions due to rapping (mg/DSCM)

$EFFR_i$ - Adjusted particle collection efficiency in each size band including rapping contributions

TEFFR - Total adjusted particle collection efficiency including rapping contributions

PCNTS - Fractions of adjusted no-rap outlet mass contained in each size band

TOTS - Sum of adjusted no-rap outlet mass fractions used to normalize PCNTS

PCNTR - Fractions of adjusted outlet mass, including rapping contributions, in each size band

TOTR - Sum of adjusted outlet mass fractions used to normalize PCNTR

APPENDIX 3

PROGRAM LISTING FOR

TI PROGRAMMABLE 59

ESP MODEL

CARD 1 and 5

STEP NUMBER	PROGRAM STEP	VARIABLE NAME FOR REFERENCE
	2N LBL A	[D_{50} or RMMD]
	2N Print	
	ln x	
	STO 36	
	R/S	[SIGMA or
	2N Print	RSIGMA]
	(	
	ln x	
	STO 38	
	*	
	(	
	2	
	*	
	π	
	)	
	$\sqrt{x}$	
	)	
	$\frac{1}{x}$	
	STO 08	[SGT 1]
	RCL 38	
25:	x^2	
	*	
	2	
	=	
	STO 38	[SGT 2]
	.01	
	ln x	
	STO 60	[ln E_0]
	67 x≥t	
	21 STO 01	
	61 STO 00	
	2N LBL ln x	

STEP NUMBER	PROGRAM STEP	VARIABLE NAME FOR REFERENCE
50:	R/S	[E_1-E_6]
	STO 2N IND 01	
	2N Print	
	ln x	
	STO 2N IND 00	
	2N OP 20	
	2N OP 21	
	RCL 00	
	INV 2N x=t lnx	
	1000	
70:	ln x	[ln E_7]
	0 STO 55	[OLDY = 0]
	STO 56	[SUM = 0]
	60 STO 00	
	61 STO 01	
	2N LBL C	
	0 STO 57	[Z]
	RCL 2N IND 01	
	x≥t	
	(	
	RCL 2N IND 01	
	-	
	RCL 2N IND 00	
100:	)	
	÷	
	6	
	=	
	STO 58	[DX]
	2N LBL 2N D'	
	RCL 58	

```
        SUM 2N IND 00      [D=D+DX]
        (
        RCL 2N IND 00
        -
        RCL 36
        )
        x²
        +/-
        ÷
        RCL 38
        =
125:    INV lnx
        *
        RCL 08
        =
        STO 59             [Y]
        *
        RCL 58
        =
        SUM 57             [Z]

        RCL 2N IND 00
        +
        .001
        =
        2N x≥t E
        GTO 2N D'

151:    2N LBL E
        RCL 59
        -
        RCL 55
        =
        *
        RCL 58
        *
        .5
        =
        INV SUM 57     [correct Z]
        RCL 57
        SUM 56             [SUM]
        STO 2N IND 00
175:    RCL 59
        STO 55         [new OLDY]
        2N OP 20
        2N OP 21
        RCL 67
        INV 2N x=t C

        61 STO 00
        16 STO 01
         0 STO 67
        66 x≠t
202:    2N LBL 2N B'
        RCL 56
        INV 2N PRD 2N IND 00
        RCL 2N IND 00
        STO 2N IND 01
        SUM 67          [sum PCNT]
        0 STO 2N IND 00
        2N OP 20
        2N OP 21
        RCL 00
        INV 2N x=t 2N B'
227:    1
        -
```

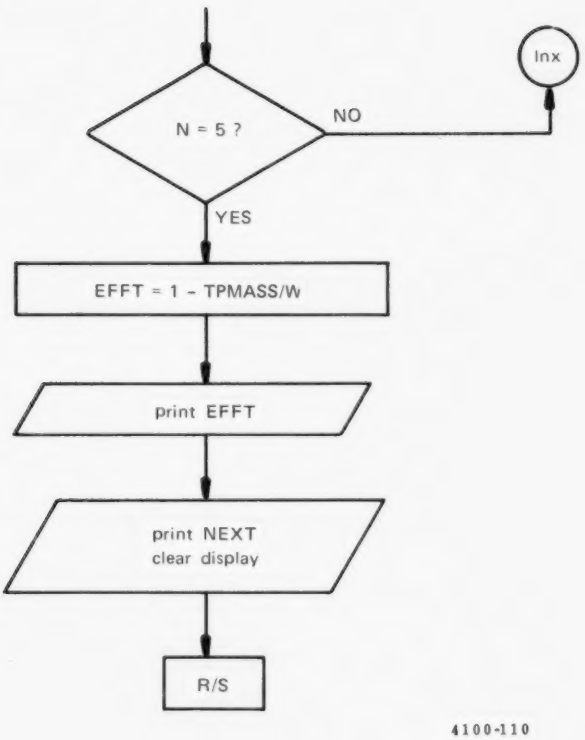


Figure 3. Flowchart for card 3 (sheet 3 of 3).

```
        RCL 67
        =
        SUM 20      [correct PCNT5]
        2N OP 05
        0
237:    R/S
```

ESP MODEL

CARD 2

```
     2N LBL A
     1.6 EE +/- 19          [E]
     STO 10
     1.38 EE +/- 23         [BC]
     STO 27
     8.85 EE +/- 12         [EPSO]
     STO 28
31:  R/S                    [DL]
     2N Print
     *
     2.29 EE +/- 3
     =
     STO 29
     R/S                    [DD]
     2N Print
     STO 30
     R/S                    [EPS]
     2N Print
50:  STO 07
     R/S                    [US]
     2N Print
     STO 08
     R/S                    [PL]
     2N Print
     *
     .305
     =
     STO 34
     R/S                    [VGS]
     2N Print
     *
     4.73 EE +/- 4
76:  =                      [VG]
     STO 09
     R/S                    [VGAS]
     2N Print
     *
     .305
     =
     STO 40
     R/S                    [TEMP °F]
     2N Print
     (
     CE
     +
     459
     )
     ÷
     1.8
102: =                      [TDK]
     STO 35
     R/S                    [P]
     2N Print
     STO 36
     R/S                    [VIS]
     2N Print
     STO 37
     R/S                    [ETAO]
     2N Print
     STO 38
     R/S                    [LINC]
     2N Print
     *
     .305
     =
125: STO 39
```

```
        21 STO 00
        22 STO 01
        11 STO 02
        16 STO 03
        25 x≷t
        RCL 29
        :
        RCL 30
151:    *
        3
        ÷
        4
        ÷
        π
        =
        STO 41              [CONST 41]

        2N LBL STO
        (
        RCL 2N IND 00
        +
        RCL 2N IND 01
        )
        *
        2.5 EE +/- 7
176:    +
        STO 2N IND 00       [RAD]
        Y^x
        3
        =
        1/x
        *
        RCL 2N IND 03       [PCNT]
        STO 2N IND 02       [PCNT]
        *
        RCL 41
        =
        STO 2N IND 03       [XNO]
        RCL 00
        2N Pause

        2N x=t EE
        2N OP 20
201:    2N OP 21
        2N OP 22
        2N OP 23
        GTO STO

        2N LBL EE
        RCL 09
        2N Prd 29           [w]
        RCL 39
        :
        RCL 40
        =                   [TINC]
        STO 40
        RCL 08
225:    *
        RCL 35
        :
        RCL 36
        :
        273
        =
        STO 08              [U]
```

```
        RCL 10
        x²
        ÷
        RCL 27
        ÷
        RCL 35
        =
        STO 27                  [VC]
250:    RCL 35
        ÷
        RCL 36
        *
        1.92 EE +/- 10
        =
        STO 42                  [ZMFP]

        21 STO 00
        43 STO 01
275:    2N LBL x⇄t
        1
        +
        RCL 42
        ÷
        RCL 2N IND 00
        *
        (
        1.26
        +
        (
        1.1
        +/-
        *
        RCL 2N IND 00
        :
300:    RCL 42
        )
        INV ln x
        *
        4
        )
        =
        STO 2N IND 01           [CCF]
        RCL 00
        2N Pause

        2N x=t 2N P→R
        2N OP 20
        2N OP 21
        GTO x⇄t

        2N LBL 2N P→R
        2N St Flg 1             [I=1]
326:    2N St Flg 3             [new section]

        0 STO 60                [for card 3]
          STO 66                  "
          STO 67                  "
          STO 41                [SW]
        100
        ÷
        (
        100
        -
        RCL 38
        )
        =
```

```
350: ln x
     *
     RCL 39
     ÷
     RCL 34
     =
     +/-
     INV lnx
     +/-
     +
     1
     =
     STO 39              [ETAPF]
     2
     *
     (
     RCL 07
     -
     1
     )
375: ÷
     (
     RCL 07
     +
     2
     )
     =
     STO 56              [CONST 56]
     662
     *
     RCL 35
     =
```

```
     √x̄
     STO 36              [VAVC]
     2N OP 05
     0
398: R/S
```

ESP MODEL

CARD 3

```
      2N LBL A
      0
      x≷t
      R/S                [LSECT]
      STO 26
      2N x=t =
      2N Print
      R/S                [A]
      2N Print
      *
      .093
      =
      STO 48
      R/S                [VOS]
      2N Print
      STO 49
      R/S                [TC]
25:   2N Print
      STO 50
      R/S                [B]
      2N Print
      *
      .0254
      =
      INV 2N Prd 49      [ERAVG]
      15.1
      *
      RCL 28
      *
      RCL 49
50:   =
      STO 55
      21 STO 00
      51 STO 01
      25 x≷t
      2N LBL Y^x
      RCL 55
      *
      (
      RCL 2N IND 00
      +
      RCL 42
75:   )
      x^2
      *
      (
      1
      +
      RCL 56
      *
      (
      RCL 2N IND 00
      :
      (
      RCL 2N IND 00
      +
      RCL 42
      )
      )
      Y^x
      3
      )
      =
100:  STO 2N IND 01      [QSAT_i]
```

```
        RCL 00
        2N Pause
        2N x=t 1/x
        2N OP 20
        2N OP 21
        GTO y^x

        2N LBL 1/x
        1 STO 07
        INV Set Flag 2
        2N OP 05
        0
124:    R/S

        2N LBL =
        11 STO 00
        16 STO 01
        21 STO 02
        50 STO 03
         0 STO 41          [TPMASS]

        25 x≥t
        INV EE
151:    2N LBL ln x
        RCL 2N IND 02
        *
        2
        =                  [DIAM]
        2N Advance
        2N Print
        RCL 2N IND 02
        y^x
        3
        *
        RCL 09
        *
        π
        *
        4
        ÷
        3
        *
        RCL 30
176:    =
        STO 42             [CONST 42]
        *
        RCL 2N IND 01
        ÷
        (
        RCL 29
        *
        RCL 2N IND 00
        )

        +/-
        +
        1
        =
        STO 2N IND 03      [EFF_i]
        2N Print

        RCL 42
        *
200:    RCL 2N IND 01
        =
        SUM 41             [TPMASS]
```

```
        RCL 02
        2N x=t 2N log x
        2N OP 20
        2N OP 21
        2N OP 22
        2N OP 23
        GTO ln x
        2N LBL 2N log x
        1
        -
        RCL 41
225:    :
        RCL 29
        =                    [EFFT]
        2N Advance
        2N Print
        2N OP 05
        0
234:    R/S
```

ESP MODEL

CARD 4

```
        2N LBL A
        20 x≥t
         0 STO 38
        51 STO 00
        16 STO 01
        2N LBL 2N Rad
        RCL 2N IND 00
        *
        RCL 2N IND 01
        =
        SUM 38                  [SUM]
26:     RCL 01

        2N x=t 2N Deg
        2N OP 20
        2N OP 21
        GTO 2N Rad

        2N LBL 2N Deg
        (
        RCL 29
        -
        RCL 41
        )
        *
        RCL 39
        =                       [DW]
        SUM 41                  [SUM SW]
51:     *
        200
        *
        RCL 26
        *
        RCL 09
        *
        RCL 38
        :
        RCL 29
        :
        RCL 50
        +
        1
        =                       [ROVRI]
        1/x
        *
75:     RCL 50
        :
        RCL 10
        :
        RCL 08
        :
        RCL 49
        :
        RCL 48
        =
        STO 38                  [AFID]

        21 STO 00
        51 STO 01
100:    60 STO 02
        65 STO 03
        31 STO 04
        43 STO 05
        16 STO 06
        2N LBL 2N B'
        2N IF FLG 3 2N Int
```

```
125:  2N IF FLG 2 2N Eng

      2N LBL 2N Int
      RCL 2N IND 01
      x⇄t
      RCL 2N IND 02
      2N x≥t C
      :
      RCL 2N IND 01
      +/-
      +
      1
      =
      1/x
      STO 57                    [CF2]
      RCL 38
      *
150:  RCL 08
      *
      RCL 10
      *
      RCL 40
      :
      4
      :
      RCL 28
      =
      STO 58                    [CF1]
      +
      RCL 57
      -
      1
      =
      :
      (
      RCL 58
176:  +
      RCL 57
      )
      *
      RCL 2N IND 01
      =
      STO 57                    [QF]
      INV 2N x≥t 2N C'
      x⇄t
      STO 57
      GTO 2N C'

      2N LBL C
      STO 57
      2N LBL 2N C'
200:  STO 2N IND 02
      30 x⇄t
      RCL 2N IND 03
      *
      (
      RCL 27
      :
      RCL 2N IND 00
      :
      4
      :
      π
      :
      RCL 28
      )
```

```
      STO 59                [V]
      :
225:  RCL 10
      =                     [ARG]
      2N x≥t D
      (
      INV ln x
      +
      RCL 27
      *
      RCL 2N IND 00
      *
      RCL 36
      *
      RCL 38
      *
      RCL 40
      :
      4
250:  :
      RCL 28
      )
      ln  x
      *
      RCL 10
      :
      RCL 59
      =                     [QT]
      2N Pause
      STO 2N IND 03         [OLDQT]
      GTO 2N D'
      2N LBL D
      RCL 2N IND 03
      2N LBL 2N D'
      +
      RCL 57
276:  =
      INV 2N IF FLG 1 E
      x⇄t
      RCL 2N IND 01         [QSAT]
      INV 2N x≥t E
      x⇄t                   [Q]

      2N LBL E
      STO 58                [Q or QSAT]
      .005 x⇄t
      RCL 58
      -
300:  RCL 2N IND 04
      =
      :
      RCL 58
      =
      2N x≥t 2N E'
      2N St Flg 2
      2N LBL 2N E'
      RCL 58
      STO 2N IND 04         [new Q]

      2N LBL 2N Eng
      (
      RCL 2N IND 04
      *
      RCL 2N IND 05
325:  *
      RCL 48
```

```
        *
        RCL 49
        ÷
        33
        :
        RCL 2N IND 00
        ÷
        RCL 37
        ÷
        RCL 09
        ÷
        RCL 26
        +/-
        )
        INV ln x
350:    2N Prd 2N IND 06        [XNO]
        INV 2N St Flg 1
        25 x⇄t
        RCL 00
        2N Pause
        2N x=t 2N Sin
        2N OP 20
        2N OP 21
        2N OP 22
        2N OP 23
        2N OP 24
        2N OP 25
375:    2N OP 26
        GTO 2N B'
        2N LBL 2N Sin
        RCL 07
        x⇄t
        RCL 26
        2N x=t 2N Cos
        2N OP 27
        GTO A
        2N LBL 2N Cos
        2N St Flg 3             [new sect]
        2N OP 05
        0
        R/S
```

CARD 6

```
      2N LBL A
      26 x≷t
      21 STO 00
      22 STO 01

      2N LBL STO
      (
      RCL 2N IND 00
      +
      RCL 2N IND 01
      *
      2.5 EE +/- 7
29:   =
      STO 2N IND 00          [RAD_i]
      2n OP 20
      2N OP 21
      RCL 00
      INV 2N x=t STO
      R/S                    [PL]
      2N Print
      STO 39
      R/S                    [PLLS]
      2N Print
      STO 41
      R/S                    [P]
50:   2N Print
      1/x
      STO 48
      R/S                    [TEMP]
      2N Print
      +
      459
      =
      :
      1.8
      *
      3670
      =
      2N Prd 48              [CONVF]
      R/S                    [NTEMP]
      2N Print
75:   STO 69
      R/S                    [SNUCK]
      2N LBL B
      2N Print
      STO 26
      R/S                    [ZIGGY]
      2N Print
      STO 27
      R/S                    [ZNUMS]
      2N Print
      STO 28
      R/S                    [ATOTAL]
      2N Print
      *
      .0929
      =
      STO 10

      .99999
      STO 08                 [TEST]
       0 STO 66
         STO 67
      50 STO 00
      31 STO 01
      43 STO 02
```

```
127:  21 STO 03
      55 STO 04
      11 STO 05
      60 STO 06
      2N LBL 2N Sin
      RCL 08
      x⇄t
      RCL 2N IND 00
150:  INV 2N x⇄t 2N Exc
      RCL 08
      STO 2N IND 00          [EFF_i]
      2N LBL 2N Exc
      +/-
      +
      1
      =
      1/x
      ln x
      *
      100
      *
      RCL 09
      :
      RCL 10
175:  =
      STO 2N IND 04          [WY_i]
      0 x⇄t
      RCL 26
      INV 2N x=t RCL
      RCL 27
      2N x=t x⇄t
      2N LBL RCL
      1
      -
      RCL 2N IND 00
      =
      STO 68                 [PEN]
      (
      1/x
200:  ln x
      *
      .0755
      *
      RCL 27
      +
      1
      +
      .766
      *
      RCL 2N IND 00
      *
      RCL 27
      Y^x
      1.786
229:  )
      *
      RCL 68
      ln x
      :
      RCL 28
      :
      (
      RCL 68
      Y^x
      RCL 28
      1/x
```

```
        *
        (
        1
        -
        RCL 26
251:    )
        +
        RCL 26
        )
        ln x
        =
        1/x
        2N PRD 2N IND 04          [WY_i]
        2N LBL x≥t
        4.4
        x≥t
        RCL 2N IND 00
        *
        2 EE 6
        =                         [DIAM]
        INV EE
276:    2N ADVANCE
        2N PRINT
        2N x≥t 2N P→R
        RCL 2N IND 03
        *
        2
        =
        ln x
        *
        .46
        +/-
        -
        4.668
        =
        2N Prd 2N IND 04          [WY_i]
300:    2N LBL 2N P→R
        RCL 10
        *
        RCL 2N IND 04
        ÷
        100
        ÷
        RCL 09
        =
        +/-
        INV ln x
        +/-
        +
        1
        =                         [EFFS_i]
        2N Print
        STO 2N IND 06
325:    *
        RCL 2N IND 05
        *
        RCL 29
        =
        SUM 66                    [TSMASS]
        2N OP 20
        2N OP 21
        2N OP 22
        2N OP 23
        2N OP 24
        2N OP 25
        2N OP 26
        16 x≥t
351:    RCL 05
        INV 2N x=t 2N Sin
```

```
        RCL 66
        :
        RCL  29
        =
        2N Advance
        2N Print
        2N Advance
        +/-
        +
        1
        =
        1/x
        ln x
        STO 65                  [EXPON]
        2N OP 05
        0
376:    R/S
```

ESP MODEL

CARD 7

```
      2N LBL A
      0 STO 67
      RCL 48
      *
      RCL 29
      :
      RCL 09
      *
      (
      RCL 65
      *
      (
      RCL 39
      -
      RCL 41
      )
25:   ÷
      RCL 39
      )
      +/-
      INV ln  x
      *
      (
      1
      -
      (
      RCL 65
      *
      RCL 41
      :
      RCL 39
      )
      +/-
      INV lnx
      )
50:   =
      STO 38                    [XMCLS]
      1 x⇄t
      RCL 69
      2N x=t √x̄
      RCL 38
      Y^X
      .894
      *
      .618
      =
      STO 42                    [RAPLOS]
      GTO 1/x

76:   2N LBL √x̄
      RCL 38
      Y^X
      .905
      *
      .155
      =
      STO 42                    [RAPLOS]
      2N LBL 1/x
      11 STO 00
      16 STO 01
103:  21 STO 02
      55 STO 03
      43 STO 04
      2N LBL 2N Cos
      0 x⇄t
      RCL 2N IND 02
```

```
      *
      2 EE 6
125:  =
      INV EE                [DIAM]
      2N Advance
      2N Print
      RCL 2N IND 00
      *
      (
      1
      -
      (
      RCL 10
      *
      RCL 2N IND 03
      ÷
      100
      ÷
      RCL 09
      +/-
150:  )
      INV lnx
      )
      -
      RCL 42
      ÷
      RCL 48
      *
      RCL 2N IND 01
      *
      RCL 09
      ÷
      RCL 29
      =
      ÷
      RCL 2N IND 00
      =
      2N x≥t 2N tan
176:  0
      2N LBL 2N tan
      2N Print
      STO 2N IND 04
      *
      RCL 2N IND 00
      *
      RCL 29
      =
      SUM 67
      2N OP 20
      2N OP 21
      2N OP 22
      2N OP 23
      2N OP 24
201:  16 x≥t
      RCL 00
      INV 2N x=t 2N Cos
      RCL 67
      ÷
      RCL 29
      =
      2N Advance
      2N Print
      2N Advance
      2N OP 05
      0
221:  R/S
```

CARD 8

```
      2N LBL A
      11 STO 00
      60 STO 01
      43 STO 02
      16 x≥t
       0 STO 65          [TOTS]
         STO 66          [TOTR]
      2N LBL B
      1
25:   -
      RCL 2N IND 01
      =
      *
      RCL 2N IND 00
      2N Print           [PCNT]
      =
      SUM 65             [TOTS]
      1
      -
      RCL 2N IND 02
      =
      *
      RCL 2N IND 00
      =
      SUM 66             [TOTR]
      2N OP 20
      2N OP 21
51:   2N OP 22
      RCL 00
      INV 2N x=t B
      2N Advance
      11 STO 00
      60 STO 01
      2N LBL C
      1
      -
      RCL 2N IND 01
      =
      *
75:   RCL 2N IND 00
      :
      RCL 65
      =
      2N Print           [PCNTS]
      2N OP 20
      2N OP 21
      RCL 00
      INV 2N x=t C
      2N Advance
      11 STO 00
      43 STO 02
100:  2N LBL D
      1
      -
      RCL 2N IND 02
      =
      *
      RCL 2N IND 00
      :
      RCL 66
      =
      2N Print           [PCNTR]
      2N OP 20
      2N OP 22
      RCL 00
      INV 2N x=t D
```

```
        2N Advance
        2N OP 05
        0
128:    R/S
```

APPENDIX 4

LOCATION OF VARIABLES

VARIABLE NAME

Location	SECTION OF MODEL 1	2	3	4	5	6	7	8
00								
01								
02								
03								
04								
05								
06								
07		EPS	increment counter					
08	SGT 1	VS→V			SGT 1	.99999		
09		VG						
10		E				ATOTAL		
11		$PCNT_{1-5}$						
12								
13								
14								
15								
16	$PCNT_{1-5}$	XNO_{1-5}			$RPCNT_{1-5}$			
17								
18								
19								
20								

VARIABLE NAME (Cont'd)

Location	SECTION OF MODEL 1	2	3	4	5	6	7	8
21	$ENDPT_{1-6}$	RAD_{1-5}			$ENDPT_{1-6}$	RAD_{1-5}		
22								
23								
24								
25								
26			LSECT					
27		BC → VC				SNUCK		
28		EPSO				ZIGGY		
29		DL → W				ZNUMS		
30		DD						
31								
32				$OLDQ_{1-5}$				
33								
34		PL						
35		TDK						
36	ln D_{50}	P → VAVC			ln RMMD			
37		VIS						
38	σ → SGT 2	ETAO		SUM → AFID	σ → SGT 2		YMCLS	
39		LINC → ETAPF				PL		
40		VGAS → TINC						

VARIABLE NAME (Cont'd)

Location	SECTION OF MODEL 1	2	3	4	5	6	7	8
41		CONST→O	TPMASS	SW		PLLS		
42		ZMPF	CONST 42				RAPLOS	
43		CCF_{1-5}					$EFFR_{1-5}$	
44								
45								
46								
47								
48			A					
49			VOS→ERAVG			CONVF		
50			EFF_{1-5}					
51			$QSAT_{1-5}$					
52								
53								
54								
55	OLDY				OLDY	WY_{1-5}		
56	SUM	CONST			SUM			
57	Z			CF2→ QF	Z			
58	DX			CF1→Q	DX			
59	Y			V	Y			

VARIABLE NAME (Cont'd)

Location	SECTION OF MODEL 1	2	3	4	5	6	7	8
60	ln ENDPT$_{0-7}$	0		$OLDQF_{1-5}$	ln ENDPT$_{0-7}$	$EFFS_{1-5}$		
61	→ 0				→ 0			
62	→ 0				→ 0			
63	→ 0				→ 0			
64	→ 0				→ 0			
65	→ 0			$OLDQT_{1-5}$	→ 0	EXPON		TOTS
66		0				TSMASS		TOTR
67	SUM→PCNT	0			SUM→PCNT	0	TRMASS	
68						PEN		
69						NTEMP		

APPENDIX 5

SAMPLE PROGRAM OUTPUT

This appendix contains a sample program output for a power station precipitator having 3 sections for an SCA of 39.3 $m^2/(m^3/sec)$ (200 $ft^2/1000$ acfm). The output is annotated so that it may be used as a reference to Section 4 of this report. Following the Programmable 59 output is a printed output for the full scale model which was run on the PDP-15 computer at Southern Research Institute. This run was made using the same 5 size bands and all estimations so that it would be equivalent to the Programmable 59 version. Following the model printout is a comparison between the efficiencies calculated by the two versions of the model (Table 3). A comparison of these efficiencies with the results of more rigorous calculations is presented in Table 4.

The efficiency differences shown in Table 3 are due to differences in the number of significant figures supported by the Programmable 59 and the PDP-15. The small differences in significant figures will compound until an effect is visible in the efficiency calculation, which, since it is an exponential relationship, is very sensitive to small changes. The differences due to changing to 16 size bands (Table 4) can be related to the different charging rates and migration velocities of large and small particles. All of the particle sizes in a given size band will be described by a single effective migration velocity. If the number of size bands is increased, the range of particle sizes in a given size band is decreased and therefore the migration velocity for that band is more representative of all of the particles in the band. Thus, the efficiency calculation for each size band is more accurate, implying that the overall efficiency calculation is also more accurate. The change to rigorous

calculation of particle charging and electric field further increases the accuracy of the calculation as these quantities are calculated by a much more exacting method which is beyond the capacity of the Programmable 59 calculator.

TI PROGRAMMABLE 59 PRINTOUT

```
  10.
   3.
  0.4
   1.
   4.
   7.
  10.
  30.
              NEXT
  2.4 00
  2.4 03
   1. 02
 2.2-04
 1.3 01
5.32 05
  5. 00
 2.8 02
  1. 00
2.28-05
 9.8 01
  1. 00
              NEXT
   6.
3.55 04
 4.8 04
7.57-01
 4.5 00
              NEXT
              NEXT
   6.
3.55 04
3.68 04
7.57-01
 4.5 00
              NEXT
              NEXT
   6. 00
3.55 04
2.55 04
7.57-01
 4.5 00
              NEXT
              NEXT
```

Card 1 input data.

Card 2 input data.

Card 3 input data for first section of ESP.

Card 3 input data for second section of ESP.

Card 3 input data for third section of ESP.

Reproduced from best available copy.

```
   0.0000007
.8084107035

   0.0000025
.9769540507

   0.0000055
0.9993778683

   0.0000085
.9999844957

     0.00002
          1.

.99252705l5
                NEXT
          6.
        2.5
        0.4
          1.
          4.
          7.
         10.
         30.
                NEXT
        1.8  01
         6.  00
         1.  00
        2.8  02
         1.  00
         0.  00
         0.  00
         3.  00
      1.065  05

        0.7
.9530622935

        2.5
.9915348979

        5.5
0.9993778683
```

Card 3 output (ideal efficiency calculation).

Particle diameter (m).
Efficiency in this size band.

Total ideal efficiency.

Card 5 input data.

Card 6 input data.

Card 6 output (adjusted efficiency without rapping).

Particle diameter (μm).
Efficiency in this size band.

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```
          8.5
.9999844957

         20.
      0.99999

.9975658176
                                    NEXT

          0.7
.9508402697

          2.5
.9890162118

          5.5
0.997247488

          8.5
0.998247135

         20.
.9990979254

.9960367336
                                    NEXT
0.016373751
.1834818112
.1694825817
.1264743322
.5041865239

.3157307453
.6380755469
.0433168656
.0008055656
.0020712766

.2030974199
.5085011066
.1177073517
.0559367987
0.114757323
```

Total adjusted efficiency without rap.

Card 7 output (adjusted efficiency with rap).

Card 8 output (fractions of particles in each size band).

Inlet.

Adjusted no-rap outlet.

Adjusted outlet with rap.

Reproduced from best available copy.

```
                                    NEXT
                0.05
                0.25
                  3.
              1.065 05

                 0.7
 .9285592121

                 2.5
 .9778781627

                 5.5
 .9936787391

                 8.5
 .9978532026

                20.
 .9979882134

 .9924141111

                                    NEXT

                 0.7
 .9244345587

                 2.5
 .9732028379

                 5.5
 .9897242094

                 8.5
 0.994628217

                20.
 0.996332295

 .9895757405

                                    NEXT
```

Card 6 input data (new non-ideal conditions).

Card 6 output (for new conditions).

Card 7 output.

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```
0.016373751
.1834818112
.1694835817
.1264743822
.5041865239

.1542012668
.5350664704
0.141229321
.0357920841
.1337108576

.1186932963
.4716682137
.1670696905
 0.06517419
.1773946095

                    NEXT
        0.1
       0.25
         3.
      1.065 05

        0.7
.9145979865

        2.5
.9684688208

        5.5
.9866741102

        8.5
.9928989889

         20.
.9930890454

.9861752255

                    NEXT
```

Card 8 output.

Card 6 input data (third set of non-ideal conditions).

Card 6 output.

Reproduced from best available copy.

```
          0.7
.9089646848

          2.5
0.962083432

          5.5
.9812731571

          8.5
.9884944208

          20.
.9908274522

0.982298682

                    NEXT
0.016373751
.1834818112
.1694835817
.1264743322
.5041865239

.1011482176
.4184804497
.1633675491
.0649627693
.2520410143

.0842078302
.3930216136
0.179302604
.0822063335
.2612616187

                    NEXT
```

Card 7 output.

Card 8 output.

Reproduced from best available copy.

FULL SCALE MODEL PRINTOUT
USING 5 SIZE BANDS AND
ALL ESTIMATIONS

```
**********************************
*                                *
*        E.P.A. ESP MODEL        *
*                                *
*   I.E.R.L.-R.T.P. AND SO.R.I.  *
*                                *
*      REVISION I,JAN. 1, 1978   *
*                                *
**********************************

PRINTOUT OF INPUT DATA FOR DATA SET NUMBER  1


DATA ON CARD NUMBER   1

NENDPT =  6   NDATA =  1

DATA ON CARD NUMBER   2

POWER STATION SCA=200 RES=4.0E+10

DATA ON CARD NUMBER   3

NEST =  2  NDIST =  2  NVI =  1  NX = 10  NY = 10  NITER =  2  NCALC =  0  NRAPD =  1  NEFF =  1  NTEMP =  1  NONID =  3

DATA ON CARD NUMBER   4

NN = 10  NUMINC = 20

DATA ON CARD NUMBER   5

DL =  2.40000 GRN/ACF  PL =  18.0000 FT  FTAD = 98.90000 %  DD =  2400.00 KG/M**3  EPS =  1.000E+02
VRATIO =   1.2000  US = 0.000220 M**2/V-SEC  FPATH =   1.0000  EBD = 1500000. V/M  RHOCGS =  4.00E+10 OHM-CM

DATA ON CARD NUMBER   6

ASNUCK( 1) = 0.00  AZIGGY( 1) = 0.00  AZNUMS( 1) =  3.0
ASNUCK( 2) = 0.05  AZIGGY( 2) = 0.25  AZNUMS( 2) =  3.0
ASNUCK( 3) = 0.10  AZIGGY( 3) = 0.25  AZNUMS( 3) =  3.0
```

DATA ON CARD NUMBER 7

ENDPT(1) = 0.400 UM ENDPT(2) = 1.000 UM ENDPT(3) = 4.000 UM ENDPT(4) = 7.000 UM ENDPT(5) = 10.000 UM
ENDPT(6) = 30.000 UM

DATA ON CARD NUMBER 8

D50 = 10.0000 UM SIGMAP = 3.0000

DATA ON CARD NUMBER 9

NUMSEC = 3 LSECT(1) = 6 LSECT(2) = 6 LSECT(3) = 6

DATA ON CARD NUMBER 10

AS(1) = 3.5466E+04 FT**2 VOS(1) = 4.8000E+04 V TCS(1) = 7.5760E-01 A WLS(1) = 1.8960E+04 FT
ACS(1) = 5.4500E-02 IN BS(1) = 4.5000E+00 IN NWS(1) = 1.2000E+01

DATA ON CARD NUMBER 11

SYS(1) = 4.5000E+00 IN VGS(1) = 5.3200E+05 FT**3/MIN VGASS(1) = 5.0000E+00 FT/SEC TEMPS(1) = 2.8000E+02 F
PS(1) = 1.0000E+00 ATM VISS(1) = 2.2790E-05 KG/M-SEC LINCS(1) = 1.0000E+00 FT

DATA ON CARD NUMBER 12

AS(2) = 3.5466E+04 FT**2 VOS(2) = 3.6750E+04 V TCS(2) = 7.5760E-01 A WLS(2) = 1.8960E+04 FT
ACS(2) = 5.4500E-02 IN BS(2) = 4.5000E+00 IN NWS(2) = 1.2000E+01

DATA ON CARD NUMBER 13

SYS(2) = 4.5000E+00 IN VGS(2) = 5.3200E+05 FT**3/MIN VGASS(2) = 5.0000E+00 FT/SEC TEMPS(2) = 2.8000E+02 F
PS(2) = 1.0000E+00 ATM VISS(2) = 2.2790E-05 KG/M-SEC LINCS(2) = 1.0000E+00 FT

DATA ON CARD NUMBER 14

AS(3) = 3.5466E+04 FT**2 VOS(3) = 2.5500E+04 V TCS(3) = 7.5760E-01 A WLS(3) = 1.8960E+04 FT
ACS(3) = 5.4500E-02 IN BS(3) = 4.5000E+00 IN NWS(3) = 1.2000E+01

DATA ON CARD NUMBER 15

SYS(3) = 4.5000E+00 IN VGS(3) = 5.3200E+05 FT**3/MIN VGASS(3) = 5.0000E+00 FT/SEC TEMPS(3) = 2.8000E+02 F

PS(3) = 1.0000E+00 ATM VISS(3) = 2.2790E-05 KG/M-SEC LINCS(3) = 1.0000E+00 FT

INCREMENTAL ANALYSIS OF PRECIPITATOR PERFORMANCE

POWER STATION SCA=200 RES=4.0E+10

CALCULATION IS IN SECTION NO. = 1 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 K
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 4.800E+04 VOLTS
CORONA WIRE RADIUS = 1.384E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 22.16

ROVRI	EPAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
3.7008	4.199E+05	2.3997E+05	2.7935E+12	23.0	1.22E-05	2.309E-03	6.341E-02	1.62E-06	2.28E-04	1
2.6113	4.199E+05	2.3997E+05	3.9592E+12	23.0	9.79E-06	1.417E-03	3.893E-02	2.03E-06	2.28E-04	2
1.9310	4.199E+05	2.3997E+05	5.3540E+12	23.0	5.51E-06	6.776E-04	1.861E-02	1.71E-06	2.28E-04	3
1.5465	4.199E+05	2.3997E+05	6.6851E+12	23.0	3.65E-06	3.615E-04	9.928E-03	1.35E-06	2.28E-04	4
1.3257	4.199E+05	2.3997E+05	7.7985E+12	23.0	2.51E-06	2.207E-04	6.061E-03	1.05E-06	2.29E-04	5
1.1965	4.199E+05	2.3997E+05	8.6404E+12	23.0	2.18E-06	1.448E-04	3.977E-03	8.17E-07	2.29E-04	6

CALCULATION IS IN SECTION NO. = 2 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 K
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 3.675E+04 VOLTS
CORONA WIRE RADIUS = 1.384E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 22.16

ROVRI	EPAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
1.0918	3.215E+05	1.8373E+05	1.2368E+13	23.0	1.99E-06	7.779E-05	2.137E-03	4.90E-07	2.29E-04	7
1.0592	3.215E+05	1.8373E+05	1.2741E+13	23.0	1.87E-06	5.870E-05	1.612E-03	4.02E-07	2.29E-04	8
1.0393	3.215E+05	1.8373E+05	1.2993E+13	23.0	1.78E-06	4.492E-05	1.234E-03	3.31E-07	2.29E-04	9
1.0260	3.215E+05	1.8373E+05	1.3162E+13	23.0	1.70E-06	3.485E-05	9.572E-04	2.75E-07	2.29E-04	10
1.0172	3.215E+05	1.8373E+05	1.3274E+13	23.0	1.64E-06	2.736E-05	7.514E-04	2.31E-07	2.29E-04	11
1.0115	3.215E+05	1.8373E+05	1.3349E+13	23.0	1.58E-06	2.169E-05	5.956E-04	1.95E-07	2.29E-04	12

CALCULATION IS IN SECTION NO. = 3 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 K
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 2.550E+04 VOLTS
CORONA WIRE RADIUS = 1.384E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 22.16

ROVRI	ERAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
1.0054	2.231E+05	1.2748E+05	1.9357E+13	23.0	1.54E-06	1.283E-05	3.415E-04	1.18E-07	2.30E-04	13
1.0038	2.231E+05	1.2748E+05	1.9387E+13	23.0	1.50E-06	1.059E-05	2.936E-04	1.06E-07	2.30E-04	14
1.0027	2.231E+05	1.2748E+05	1.9409E+13	23.0	1.47E-06	9.218E-06	2.532E-04	9.50E-08	2.30E-04	15
1.0019	2.231E+05	1.2748E+05	1.9424E+13	23.0	1.44E-06	7.974E-06	2.190E-04	8.57E-08	2.30E-04	16
1.0013	2.231E+05	1.2748E+05	1.9435E+13	23.0	1.41E-06	6.916E-06	1.900E-04	7.70E-08	2.30E-04	17
1.0009	2.231E+05	1.2748E+05	1.9442E+13	23.0	1.38E-06	6.009E-06	1.650E-04	6.97E-08	2.30E-04	18

EST. EFFICIENCY = 98.90 UNCORRECTED COMPUTED EFFICIENCY = 99.15

INCREMENTAL ANALYSIS OF PRECIPITATOR PERFORMANCE

POWER STATION SCA=200 RES=4.0E+10

CALCULATION IS IN SECTION NO. = 1 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 K
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 4.800E+04 VOLTS
CORONA WIRE RADIUS = 1.384E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 23.27

ROVRI	ERAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
3.8363	4.199E+05	2.3997E+05	2.6948E+12	23.0	1.22E-05	2.279E-03	6.261E-02	1.57E-06	2.28E-04	1
2.6753	4.199E+05	2.3997E+05	3.8644E+12	23.0	9.86E-06	1.427E-03	3.920E-02	2.01E-06	2.28E-04	2
1.9555	4.199E+05	2.3997E+05	5.2867E+12	23.0	5.59E-06	6.864E-04	1.885E-02	1.71E-06	2.28E-04	3
1.5531	4.199E+05	2.3997E+05	6.6568E+12	23.0	3.68E-06	3.658E-04	1.005E-02	1.35E-06	2.28E-04	4
1.3249	4.199E+05	2.3997E+05	7.8032E+12	23.0	2.54E-06	2.230E-04	6.123E-03	1.06E-06	2.29E-04	5
1.1932	4.199E+05	2.3997E+05	8.6645E+12	23.0	2.18E-06	1.462E-04	4.015E-03	8.22E-07	2.29E-04	6

CALCULATION IS IN SECTION NO. = 2 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 M
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 3.675E+04 VOLTS
CORONA WIRE RADIUS = 1.384E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 23.27

ROVRI	ERAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
1.0849	3.215E+05	1.8373E+05	1.2400E+13	23.0	1.99E-06	7.848E-05	2.155E-03	4.93E-07	2.29E-04	7
1.0572	3.215E+05	1.8373E+05	1.2773E+13	23.0	1.87E-06	5.920E-05	1.626E-03	4.04E-07	2.29E-04	8
1.0370	3.215E+05	1.8373E+05	1.3022E+13	23.0	1.78E-06	4.528E-05	1.244E-03	3.33E-07	2.29E-04	9
1.0241	3.215E+05	1.8373E+05	1.3186E+13	23.0	1.70E-06	3.512E-05	9.647E-04	2.77E-07	2.29E-04	10
1.0158	3.215E+05	1.8373E+05	1.3294E+13	23.0	1.64E-06	2.756E-05	7.570E-04	2.32E-07	2.29E-04	11
1.0104	3.215E+05	1.8373E+05	1.3365E+13	23.0	1.58E-06	2.185E-05	6.000E-04	1.95E-07	2.29E-04	12

CALCULATION IS IN SECTION NO. = 3 AND THE SECTION LENGTH IS = 1.8300 M

COLLECTION AREA = 3.298E+03 M2
WIRE TO PLATE = 1.143E-01 M
CURRENT/M = 1.310E-04 AMP/M
1/2 WIRE TO WIRE = 1.143E-01 M
TEMPERATURE = 410.556 K
ION MOBILITY = 3.307E-04 M2/VOLT-SEC
DUST WEIGHT = 1.383E+00 KG/SEC

APPLIED VOLTAGE = 2.550E+04 VOLTS
CORONA WIRE RADIUS = 1.334E-03 M
CURRENT DENSITY = 2.297E-04 AMP/M2
GAS FLOW RATE = 2.516E+02 M3/SEC
PRESSURE = 1.000 ATM
MEAN THERMAL SPEED = 5.213E+02 M/SEC
LENGTH INCR. =0.30500000 M

TOTAL CURRENT = 7.576E-01 AMPS
CORONA WIRE LENGTH = 5.783E+03 M
DEPOSIT E FIELD = 9.188E+04 VOLT/M
GAS VELOCITY = 1.525E+00 M/SEC
VISCOSITY = 2.279E-05 KG/M-SEC
PART. PATH PARAM. = 7.873E-08 M
INPUT EFF./INCR. = 23.27

ROVRI	ERAVG	EPLT	AFID	CMCD	MMD	WEIGHT	DUST LAYER	J(PART)	J(ION)	INCR. NO.
1.0048	2.231E+05	1.274BE+05	1.936BE+13	23.0	1.54E-06	1.252E-05	3.439E-04	1.18E-07	2.30E-04	13
1.0033	2.231E+05	1.274BE+05	1.9396E+13	23.0	1.51E-06	1.07AE-05	2.957E-04	1.06E-07	2.30E-04	14
1.0023	2.231E+05	1.274BE+05	1.9416E+13	23.0	1.47E-06	9.283E-06	2.550E-04	9.55E-08	2.30E-04	15
1.0016	2.231E+05	1.274BE+05	1.9429E+13	23.0	1.44E-06	8.030E-06	2.205E-04	8.60E-08	2.30E-04	16
1.0011	2.231E+05	1.274BE+05	1.9439E+13	23.0	1.41E-06	6.964E-06	1.913E-04	7.77E-08	2.30E-04	17
1.0008	2.231E+05	1.274BE+05	1.9445E+13	23.0	1.38E-06	6.050E-06	1.662E-04	7.00E-08	2.30E-04	18

CHARGING RATES FOR PARTICLE SIZES FROM SUBROUTINE CHAPGN OR CHGSUM

SUM OF CLASSICAL FIELD AND DIFFUSIONAL CHARGES USED FOR PARTICLE CHARGING

INCREMENT NO. Q/QSATF FOR INDICATED PARTICLE SIZES

	0.7000E-06	0.2500E-05	0.5500E-05	0.8500E-05	0.2000E-04
1	1.1591	0.9767	0.9140	0.8930	0.8862
2	1.6693	1.4148	1.3361	1.3091	1.2770
3	1.9813	1.6571	1.5670	1.5366	1.5009
4	2.1414	1.7993	1.7006	1.6676	1.6292
5	2.2599	1.8877	1.7822	1.7472	1.7067
6	2.3426	1.9459	1.8368	1.7983	1.7560
7	2.3796	1.9568	1.8398	1.8015	1.7573
8	2.4087	1.9653	1.8398	1.8015	1.7573
9	2.4326	1.9653	1.8398	1.8015	1.7573
10	2.4529	1.9653	1.8398	1.8015	1.7573
11	2.4704	1.9653	1.8398	1.8015	1.7573
12	2.4858	1.9653	1.8398	1.8015	1.7573
13	2.5051	1.9653	1.8398	1.8015	1.7573
14	2.5218	1.9653	1.8398	1.8015	1.7573
15	2.5366	1.9653	1.8398	1.8015	1.7573
16	2.5497	1.9653	1.8398	1.8015	1.7573
17	2.5616	1.9653	1.8398	1.8015	1.7573
18	2.5616	1.9653	1.8398	1.8015	1.7573

CHARGE ACCUMULATED ON PARTICLE SIZES IN EACH INCREMENT

INCREMENT	CHARGE FOR INDICATED PARTICLE SIZES				
	0.7000E-06	0.2500E-05	0.5500E-05	0.8500E-05	0.2000E-04
1	0.13042E-16	0.13432E-15	0.60673E-15	0.14135E-14	0.75872E-14
2	0.18784E-16	0.19457E-15	0.88605E-15	0.20721E-14	0.11185E-13
3	0.22069E-16	0.22789E-15	0.10392E-14	0.24322E-14	0.13146E-13
4	0.24096E-16	0.24748E-15	0.11277E-14	0.26396E-14	0.14270E-13
5	0.25430E-16	0.25960E-15	0.11816E-14	0.27656E-14	0.14948E-13
6	0.26360E-16	0.26760E-15	0.12168E-14	0.28463E-14	0.15380E-13
7	0.26776E-16	0.26910E-15	0.12201E-14	0.28514E-14	0.15392E-13
8	0.27104E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
9	0.27373E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
10	0.27601E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
11	0.27798E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
12	0.27971E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
13	0.28188E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
14	0.28377E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
15	0.28542E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
16	0.28690E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
17	0.28824E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13
18	0.28824E-16	0.27027E-15	0.12201E-14	0.28514E-14	0.15392E-13

PARTICLE SIZE RANGE STATISTICS

CORRECTIONS FOR NONIDEALITIES USING SET NO. 1 OF CORRECTION PARAMETERS

SIZE	CCF	INLET %	OUTLET %	COR. OUTLET %	NO-RAP EFF.	NO-RAP W	NO-RAP P	COR. EFF.	COR. W	COR. P
7.000E-07	1.283	1.635	31.6486	20.9155	94.3406	7.303	5.6594	94.0952	7.195	5.9048
2.500E-06	1.079	18.408	63.6580	51.4586	98.9890	11.683	1.0110	98.7096	11.063	1.2904
5.500E-06	1.036	17.059	4.5806	11.6191	99.9215	18.182	0.0785	99.6856	14.654	0.3144
8.500E-06	1.023	12.728	0.0998	5.3658	99.9977	27.168	0.0023	99.8054	15.874	0.1946
2.000E-05	1.010	50.170	0.0170	10.6409	99.9999	46.130	0.0001	99.9021	17.621	0.0979

EFFICIENCY - STATED = 99.15 COMPUTED = 99.1458 CONVERGENCE OBTAINED

ADJUSTED NO-RAP EFF. = 99.7076
MMD OF INLET SIZE DISTRIBUTION = 1.000E+01
SIGMAP OF INLET SIZE DISTRIBUTION = 3.000E+00
MMD OF EFFLUENT UNDER NO-RAP CONDITIONS = 1.360E+00
SIGMAP OF EFFLUENT UNDER NO-RAP CONDITIONS = 1.904E+00
LOG-NORMAL GOODNESS OF FIT = 1.000
PRECIPITATION RATE PARAMETER UNDER NO-RAP CONDITIONS = 14.838

SIGMAG= 0.000 WITH 0.000 SNEAKAGE OVER 3.000 STAGES
NTEMP = 1
RMMD = 6.00
RSIGMA = 2.50
CORR. EFF. = 99.5384
CORRECTED MMD OF EFFLUENT = 2.335E+00
CORRECTED SIGMAP OF EFFLUENT = 3.027E+00
LOG-NORMAL GOODNESS OF FIT = 0.996
CORRECTED PRECIPITATION RATE PARAMETER = 13.68

UNADJUSTED MIGRATION VELOCITIES AND EFFICIENCIES, AND DISCRETE OUTLET MASS LOADINGS

IDEAL UNADJUSTED MIG. VEL.(CM/SEC)	IDEAL UNADJUSTED EFFICIENCY(%)	NO-RAP DM/DLOGD(MG/DSCM)	RAPPING PUFF DM/DLOGD(MG/DSCM)	NO-RAP+RAP PUFF DM/DLOGD(MG/DSCM)	RAPPING PUFF DISTRIBUTION(%)	PARTICLE DIAM.(M)
3.948E+00	7.883E+01	1.926E+01	8.350E-01	2.009E+01	2.370E+00	7.000E-07
9.199E+00	9.731E+01	2.560E+01	7.073E+00	3.267E+01	3.038E+01	2.500E-06
1.818E+01	9.992E+01	4.563E+00	1.371E+01	1.827E+01	2.377E+01	5.500E-06
2.717E+01	1.000E+02	1.560E-01	1.309E+01	1.324E+01	1.446E+01	8.500E-06
4.613E+01	1.000E+02	8.636E-03	8.525E+00	8.534E+00	2.902E+01	2.000E-05

SUMMARY TABLE OF ESP OPERATING
PARAMETERS AND PERFORMANCE

DATA SET NUMBER 1

ESP PERFORMANCE: EFFICIENCY = 99.5384 % SCA = 3.932E+01 M**2/(M**3/SEC)

ELECTRICAL CONDITIONS: AVG. APPLIED VOLTAGE = 3.675E+04 V
AVG. CURRENT DENSITY = 22.97 NA/CM**2
RESISTIVITY = 4.000E+10 OHM-CM

SIZE DISTRIBUTIONS: INLET MMD = 1.000E+01 UM INLET SIGMAP = 3.000E+00
OUTLET MMD = 2.335E+00 UM OUTLET SIGMAP = 3.027E+00

NONIDEAL PARAMETERS: GAS SNEAKAGE FRACTION = 0.00 /SECTION GAS VELOCITY SIGMAG = 0.00
RAPPING MMD = 6.000E+00 UM RAPPING SIGMAP = 2.500E+00

PARTICLE SIZE RANGE STATISTICS

CORRECTIONS FOR NONIDEALITIES USING SET NO. 2 OF CORRECTION PARAMETERS

SIZE	CCF	INLET %	OUTLET %	COR. OUTLET %	NO-RAP EFF.	NO-RAP N	NO-RAP P	COR. EFF.	COR. N	COR. P
7.000E-07	1.283	1.635	17.9727	13.7194	91.6899	6.326	8.3101	91.2792	6.204	8.7208
2.500E-06	1.079	18.408	60.8329	52.5311	97.5017	9.583	2.4983	97.0341	8.946	2.9659
5.500E-06	1.036	17.059	15.8158	17.9836	99.2992	12.615	0.7008	98.9043	11.479	1.0957
8.500E-06	1.023	12.728	5.8682	6.7556	99.7702	15.451	0.2298	99.4484	13.224	0.5516
2.000E-05	1.010	50.170	1.5124	9.0103	99.9772	21.328	0.0228	99.8133	15.980	0.1867

EFFICIENCY - STATED = 99.15 COMPUTED = 99.1458 CONVERGENCE OBTAINED

ADJUSTED NO-RAP EFF. = 99.2440
MMD OF INLET SIZE DISTRIBUTION = 1.000E+01
SIGMAP OF INLET SIZE DISTRIBUTION = 3.000E+00
MMD OF EFFLUENT UNDER NO-RAP CONDITIONS = 2.052E+00
SIGMAP OF EFFLUENT UNDER NO-RAP CONDITIONS = 2.126E+00
LOG-NORMAL GOODNESS OF FIT = 0.999
PRECIPITATION RATE PARAMETER UNDER NO-RAP CONDITIONS = 12.423

SIGMAG= 0.250 WITH 0.050 SNEAKAGE OVER 3.000 STAGES
NTEMP = 1
RMMD = 6.00
RSIGMA = 2.50
CORR. EFF. = 98.9607
CORRECTED MMD OF EFFLUENT = 2.762E+00
CORRECTED SIGMAP OF EFFLUENT = 2.561E+00
LOG-NORMAL GOODNESS OF FIT = 1.000
CORRECTED PRECIPITATION RATE PARAMETER = 11.61

UNADJUSTED MIGRATION VELOCITIES AND EFFICIENCIES, AND DISCRETE OUTLET MASS LOADINGS

IDEAL UNADJUSTED MIG. VEL.(CM/SEC)	IDEAL UNADJUSTED EFFICIENCY(%)	NO-RAP DM/DLOGD(MG/DSCM)	RAPPING PUFF DM/DLOGD(MG/DSCM)	NO-RAP+RAP PUFF DM/DLOGD(MG/DSCM)	RAPPING PUFF DISTRIBUTION(%)	PARTICLE DIAM.(M)
3.948E+00	7.883E+01	2.829E+01	1.398E+00	2.967E+01	2.370E+00	7.000E-07
9.199E+00	9.731E+01	6.326E+01	1.184E+01	7.510E+01	3.038E+01	2.500E-06
1.81PE+01	9.992E+01	4.074E+01	2.295E+01	6.369E+01	2.377E+01	5.500E-06
2.717E+01	1.000E+02	1.563E+01	2.190E+01	3.754E+01	1.446E+01	8.500E-06
4.013E+01	1.000E+02	1.985E+00	1.427E+01	1.625E+01	2.902E+01	2.000E-05

SUMMARY TABLE OF ESP OPERATING
PARAMETERS AND PERFORMANCE

DATA SET NUMBER 2

ESP PERFORMANCE: EFFICIENCY = 98.9607 % SCA = 3.932E+01 M**2/(M**3/SEC)

ELECTRICAL CONDITIONS: AVG. APPLIED VOLTAGE = 3.675E+04 V
AVG. CURRENT DENSITY = 22.97 NA/CM**2
RESISTIVITY = 4.000E+10 OHM-CM

SIZE DISTRIBUTIONS: INLET MMD = 1.000E+01 UM INLET SIGMAP = 3.000E+00
OUTLET MMD = 2.762E+00 UM OUTLET SIGMAP = 2.561E+00

NONIDEAL PARAMETERS: GAS SNEAKAGE FRACTION = 0.05 /SECTION GAS VELOCITY SIGMAG = 0.25
RAPPING MMD = 6.000E+00 UM RAPPING SIGMAP = 2.500E+00

PARTICLE SIZE RANGE STATISTICS

CORRECTIONS FOR NONIDEALITIES USING SET NO. 3 OF CORRECTION PARAMETERS

SIZE	COF	INLET %	OUTLET %	COR. OUTLET %	NO-RAP EFF.	NO-RAP A	NO-RAP P	COR. EFF.	COR. A	COR. P
7.000E-07	1.283	1.635	13.2552	10.7478	90.1921	5.905	9.8079	89.6671	5.772	10.3329
2.500E-06	1.079	18.408	53.1690	47.0190	96.5056	8.529	3.4944	95.9080	8.128	4.0920
5.500E-06	1.036	17.059	20.1580	20.9909	98.5704	10.802	1.4296	98.0657	10.033	1.9343
8.500E-06	1.023	12.723	7.7044	9.2607	99.2677	12.503	0.7323	98.8563	11.370	1.1437
2.000E-05	1.010	50.170	5.7133	11.0817	99.8622	16.752	0.1378	99.6528	14.401	0.3472

EFFICIENCY - STATED = 99.15 COMPUTED = 99.1458 CONVERGENCE OBTAINED

ADJUSTED NO-RAP EFF. = 98.7902
MMD OF INLET SIZE DISTRIBUTION = 1.000E+01
SIGMAP OF INLET SIZE DISTRIBUTION = 3.000E+00
MMD OF EFFLUENT UNDER NO-RAP CONDITIONS = 2.662E+00
SIGMAP OF EFFLUENT UNDER NO-RAP CONDITIONS = 2.366E+00
LOG-NORMAL GOODNESS OF FIT = 0.999
PRECIPITATION RATE PARAMETER UNDER NO-RAP CONDITIONS = 11.227

SIGMAG= 0.250 WITH 0.100 BREAKAGE OVER 5.000 STAGES
NTEMP = 1
MMD = 6.00
RSIGMA = 2.50
CORR. EFF. = 98.4280
CORRECTED MMD OF EFFLUENT = 3.218E+00
CORRECTED SIGMAP OF EFFLUENT = 2.551E+00
LOG-NORMAL GOODNESS OF FIT = 1.000
CORRECTED PRECIPITATION RATE PARAMETER = 10.56

UNADJUSTED MIGRATION VELOCITIES AND EFFICIENCIES, AND DISCRETE OUTLET MASS LOADINGS

IDEAL UNADJUSTED MIG. VEL.(CM/SEC)	IDEAL UNADJUSTED EFFICIENCY(%)	NO-RAP DM/DLOGD(MG/DSCM)	RAPPING PUFF DM/DLOGD(MG/DSCM)	NO-RAP+RAP PUFF DM/DLOGD(MG/DSCM)	RAPPING PUFF DISTRIBUTION(%)	PARTICLE DIAM.(M)
3.988E+00	7.883E+01	3.337E+01	1.786E+00	3.516E+01	2.370E+00	7.000E-07
9.199E+00	9.731E+01	8.408E+01	1.513E+01	1.036E+02	3.038E+01	2.500E-06
1.818E+01	9.992E+01	8.310E+01	2.033E+01	1.124E+02	2.377E+01	5.500E-06
2.717E+01	1.000E+02	4.983E+01	2.799E+01	7.782E+01	1.446E+01	8.500E-06
4.613E+01	1.000E+02	1.200E+01	1.824E+01	3.023E+01	2.902E+01	2.000E-05

SUMMARY TABLE OF ESP OPERATING
PARAMETERS AND PERFORMANCE

DATA SET NUMBER 3

ESP PERFORMANCE: EFFICIENCY = 98.4280 % SCA = 3.932E+01 M**2/(M**3/SEC)

ELECTRICAL CONDITIONS: AVG. APPLIED VOLTAGE = 3.675E+04 V
AVG. CURRENT DENSITY = 22.97 NA/CM**2
RESISTIVITY = 4.000E+10 OHM-CM

SIZE DISTRIBUTIONS: INLET MMD = 1.000E+01 UM INLET SIGMAP = 3.000E+00
OUTLET MMD = 3.214E+00 UM OUTLET SIGMAP = 2.551E+00

NONIDEAL PARAMETERS: GAS SNEAKAGE FRACTION = 0.10 /SECTION GAS VELOCITY SIGMAG = 0.25
RAPPING MMD = 6.000E+00 UM RAPPING SIGMAP = 2.500E+00

STOP 011111

TABLE 3. COMPARISON OF THE RESULTS OF THE PROGRAMMABLE 59 AND FULL SCALE MODELS WITH THE SAME RUNNING CONDITIONS

Ideal Efficiency: PDP - 99.15%
TI - 99.25%

Corrected Efficiency:

Corrections	Size μm	No Rap Efficiency (%) TI	No Rap Efficiency (%) PDP	Rap Efficiency (%) TI	Rap Efficiency (%) PDP
SNUCK = 0.0	.7	95.3	94.3	95.1	94.1
ZIGGY = 0.0	2.5	99.2	99.0	98.9	98.7
	5.5	99.9	99.9	99.7	99.7
	8.5	99.99	99.99	99.83	99.80
	20.0	99.99	99.99	99.91	99.90
		99.76	99.71	99.60	99.53
SNUCK = 0.05	.7	92.8	91.7	92.4	91.3
ZIGGY = 0.25	2.5	97.8	97.5	97.3	97.0
	5.5	99.4	99.3	99.0	98.9
	8.5	99.8	99.8	99.46	99.45
	20.0	99.8	99.98	99.64	99.81
		99.24	99.24	98.96	98.96
SNUCK = 0.10	.7	91.5	90.2	90.9	89.7
ZIGGY = 0.25	2.5	96.8	96.5	96.2	95.9
	5.5	98.7	98.6	98.1	98.1
	8.5	99.3	99.3	98.85	98.86
	20.0	99.3	99.86	99.09	99.65
		98.62	98.79	98.23	98.43

TABLE 4. COMPARISON OF THE RESULTS OF THE PROGRAMMABLE 59 AND FULL SCALE MODELS WITH DIFFERENT RUNNING CONDITIONS

DEFINITIONS: 5E--PDP-15, 5 size bands, all estimations
16E--PDP-15, 16 size bands, all estimations
16R--PDP-15, 16 size bands, rigorous calculations

OVERALL EFFICIENCY

Corrections	No Rap Efficiency (%)				Rap Efficiency (%)			
	TI	5E	16E	16R	TI	5E	16E	16R
Ideal (no corrections)	99.25	99.15	98.66	99.97				
SNUCK = 0.0 ZIGGY = 0.0	99.76	99.71	99.57	99.20	99.60	99.53	99.36	98.91
SNUCK = 0.05 ZIGGY = 0.25	99.24	99.24	98.94	98.40	98.98	98.96	98.60	97.98
SNUCK = 0.10 ZIGGY = 0.25	98.62	98.79	98.37	97.77	98.23	98.43	97.95	97.28

APPENDIX 6

FORTRAN LISTING FOR EQUIVALENT ALL-APPROXIMATIONS ESP MODEL

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C
C                  ***********************************
C                  *                                 *
C                  *       E.P.A. ESP MODEL          *
C                  *                                 *
C                  ***********************************
C
C    VERSION FOR MICRO-ESP
C
      REAL  NWIRE,        JPART,JION,LINC,NWS
      DIMENSION CHKSUM(20)
      COMMON/BLK1/DIAM(20),ONO(20),DXS(20),XMV(20),PCNT(20),RAD(20),
     1CCF(20),PRCU(21)
      COMMON/BLK2/LSECT(10),EFF(20),EFFS(20),EFFR(20),PRCR(21)
      COMMON/BLK3/VG,ATOTAL,DD,ETAO,DL,PL,RHO
      COMMON/BLK4/NS
      COMMON/BLK5/TDK,NUMSEC
      COMMON/BLK6/VOL(20),XNO(20),O(20),WS(20),          DW(45),AS(10),
     1VOS(10),TCS(10),WLS(10),ACS(10),BS(10),SYS(10),
     2                    QSAT(20),U,E,EPSO,PI,ERAVG,BC,TEMP,EPS,VAVC
      COMMON/BLK7/XDC(45,20)
      COMMON/BLK11/ENDPT(21),NENDPT
      COMMON/BLK14/TMFP,WY(20),RPCNT(20),PCNTS(20),PCNTR(20),PCUS(21),
     $PCUR(21)
      COMMON/BLK15/NPRINT,NSECT,SLNGTH,A,VO,TC,B,AC,WL,CL,CD,ET,SY,
     1VGAS,P,VIS,W,LINC,XPI,EPLT,AFID,XCD,ZMD,
     2WT,LTHICK,JPART,JION,I,ROVRI
      COMMON/BLK16/   VRATIO,NF
      COMMON/BLK17/NREAD,NPRNT
      COMMON/BLK19/DV,NX,NITER,US,NDSET,
     1NWS(10),D50,SIGMAP
      COMMON/BLK20/SCHARG,CHRFID,TIMEI,TIMEF,V,FACTRE,RSIZE,CRUMBR,J,
     1ITER,OLDQF(20),OLDQT(20),SOLDQF(20),SOLDQT(20)
      NREAD=2
      NPRNT=3
      CALL ERRSET(10)
C
C    CONSTANTS
C
      PI = 3.1415927
      E = 1.6E-19
      BC=1.38E-23
      EPSO = 8.85E-12
      CMKS=4.*PI*EPSO
C
C
      READ(NREAD,3)NENDPT,NDIST
    3 FORMAT(2I2)
      WRITE(NPRNT,2100)NENDPT,NDIST
 2100 FORMAT('1 INPUT DATA'//'0',2I10)
      NS=NENDPT-1
      READ(NREAD,4) (ENDPT(I),I=1,NENDPT)
    4 FORMAT(8F10.0)
      WRITE(NPRNT,2110)(ENDPT(I),I=1,8)
 2110 FORMAT('0',8F10.3)
      IF(9.GT.NENDPT)GO TO 4739
      WRITE(NPRNT,2110)(ENDPT(I),I=9,16)
      IF(17.GT.NENDPT)GO TO 4739
      WRITE(NPRNT,2110)(ENDPT(I),I=17,21)
 4739 DO 4740 I=1,NS
```

```
      RAD(I)=((ENDPT(I)+ENDPT(I+1))/2.)*1.E-06/2.
 4740 CONTINUE
      IF(NDIST.EQ.1)GO TO 772
      READ(NREAD,8533) D50,SIGMAP
 8533 FORMAT(2F10.0)
      WRITE(NPRNT,2110)D50,SIGMAP
      CALL LNDIST(D50,SIGMAP,PRCU,PCNT)
      GO TO 771
  772 READ(NREAD,4)(PRCU(I),I=1,NENDPT)
      WRITE(NPRNT,2110)(PRCU(I),I=1,8)
      IF(9.GT.NENDPT)GO TO 4741
      WRITE(NPRNT,2110)(PRCU(I),I=9,16)
      IF(17.GT.NENDPT)GO TO 4741
      WRITE(NPRNT,2110)(PRCU(I),I=17,21)
 4741 DO 33 J=1,NS
   33 PCNT(J) = (PRCU(J+1)-PRCU(J))/100.
      CALL LNFIT(PRCU,D50,SIGMAP,GFIT)
  771 CONTINUE
      READ(NREAD,5)DL,DD,EPS,US,NONID
    5 FORMAT(4F10.0,I2)
      WRITE(NPRNT,2130)DL,DD,EPS,US,NONID
 2130 FORMAT('0',4E10.3,8X,I2)
      READ(NREAD,7)PL,VG,VGAS,TDK,P,VIS,ETAO,LINC
    7 FORMAT(8F10.0)
      WRITE(NPRNT,2140)PL,VG,VGAS,TDK,P,VIS,ETAO,LINC
 2140 FORMAT('0',8E10.3)
C
C         CONVERSION
C
      PL = PL * 0.305
      DL = DL * 2.29E-03
      DV = DL / DD
      VG=VG*4.73E-04
      VGAS=VGAS*.305
      TDK=(TDK+459.)/1.8
      LINC=LINC*.305
      ZMFP=(8.205E-05*TDK)/(1.414*PI*1.6E-19*6.02E+23*P)
      THFP=ZMFP
      VAVC=SQRT((8.*8.314E+07*TDK)/(3.14*32.))/100.
      VC=E**2/(BC*TDK)
      U=(TDK/273.16)*US*(1.0/P)
      TINC=LINC/VGAS
      W = DL*VG
      READ(NREAD,770) NUMSEC,(LSECT(I),I=1,NUMSEC)
  770 FORMAT(I2,10I2)
      PLLS = LINC*FLOAT(LSECT(NUMSEC))
      ATOTAL = 0.
      NF = 0
      DO 1143 NSECT=1,NUMSEC
      NF = NF + LSECT(NSECT)
      READ(NREAD,762)AS(NSECT),VOS(NSECT),TCS(NSECT),BS(NSECT)
  762 FORMAT(4E10.3)
      ATOTAL = ATOTAL+AS(NSECT)*.0929
      WRITE(NPRNT,2140)AS(NSECT),VOS(NSECT),TCS(NSECT),BS(NSECT)
 1143 CONTINUE
      DO 9 I = 1, NS
      VOL(I) = PCNT(I) * DV
      ONO(I) = VOL(I)/(4./3.*PI*RAD(I)**3)
      XNO(I) = ONO(I)
      TST = -1.1*RAD(I)/ZMFP
```

```
      IF(TST.LE.-87.)TST=-87.
      CCF(I) = 1+(ZMFP/RAD(I))*(1.257+.4*EXP(TST))
    9 CONTINUE
      INDEX=0
      NSECT=1
      NCOOP=0
C*****************************************************************************
      DO 3000 I=1,NF
      INDEX=INDEX+1
      IF(I.EQ.1) GO TO 761
      IF(INDEX-LSECT(NSECT)) 760,760,761
  761 CONTINUE
      NCOOP=1
      NPRINT=1
      IF(I.EQ.1) GO TO 760
      NSECT=NSECT+1
      INDEX=1
  760 CONTINUE
      IF(NCOOP.NE.1) GO TO 764
      A=AS(NSECT)*9.3E-02
      VO=VOS(NSECT)
      TC=TCS(NSECT)
      B=BS(NSECT)*2.54E-02
      ERAVG=VO/B
      DO 6989 L=1,NS
      QSAT(L)=(4.*PI*EPSO*(RAD(L)+TMFP)**2)*ERAVG*(1.+2.*((EPS-1.)/
     1(EPS+2.))*(RAD(L)/(RAD(L)+TMFP))**3)*1.2
 6989 CONTINUE
      NCOOP=0
      CD = TC / A
  764 CONTINUE
      CALL SPCHG1(SW,ROVRI,OROVRI,XS,ETAPF,DW,QSAT,XNO,W,LSECT,IC,VG,
     1EIAO,FID,AFID,AVGFID,XCD,U,UEQ,I,NSECT,LINC,PL,CD,E,ERAVG,NS,XPI)
      CHRFID=AFID
C*****************************************************************************
      DO 2900 J = 1, NS
      IF(J.GT.1) GO TO 428
      TIMEI=FLOAT(I-1)*TINC
      TIMEF=FLOAT(I)*TINC
  428 CONTINUE
      RSIZE=RAD(J)
      SCHARG=QSAT(J)/1.6E-19
      V=VC/(RSIZE*CMKS)
      IF(I.LE.2) GO TO 5850
      IF(I.EQ.3) GO TO 5853
      IF(NSECT.EQ.1) GO TO 5680
      IF((INDEX.EQ.1).AND.(VOS(NSECT).GT.VOS(NSECT-1))) GO TO 5850
 5680 CONTINUE
      IF(CHKSUM(J).LE.0.005) GO TO 5854
 5853 CONTINUE
      CHKSUM(J)=(XDC(I-1,J)-XDC(I-2,J))/XDC(I-1,J)
      IF(NSECT.EQ.1) GO TO 5681
      IF((INDEX.EQ.1).AND.(VOS(NSECT).GT.VOS(NSECT-1))) GO TO 5850
 5681 CONTINUE
      IF(CHKSUM(J).GT.0.005) GO TO 5850
 5854 CONTINUE
      Q(J)=XDC(I-1,J)
      GO TO 5855
 5850 CONTINUE
      CALL CHGSUM
```

```
      Q(J)=CNUMBR*1.6E-19
      IF((TIME1.EQ.0.).AND.(CNUMBR.GT.SCHARG)) Q(J)=SCHARG*1.6E-19
 5855 CONTINUE
      XDC(I,J)=Q(J)
C
 2900 CONTINUE
      IF(UEQ.LT.1.0E-4)UEQ=1.0E-4
      IF(INDEX.EQ.1) GO TO 377
      IF(UEQ.NE.1.0E-4) GO TO 9133
      EPLT=SKIP
      GO TO 9132
 9133 CONTINUE
      SIGMA=OROVRI-ROVRI
      SIGMA=ABS(SIGMA)
      IF(SIGMA.LT..01) GO TO 9132
  377 CONTINUE
      EPLT=ERAVG/1.75
      SKIP=EPLT
 9132 OROVRI=ROVRI
C
      DO 2965 J=1,NS
      XMV(J)=CCF(J)*Q(J)*EPLT/(6.*PI*RAD(J)*VIS)
      EMV=XMV(J)
      X=(-A*EMV)/(VG*FLOAT(LSECT(NSECT)))
      EFFX=  1. - EXP( X )
      DXNO=XNO(J)*EFFX
      XNO(J)=XNO(J)-DXNO
 2965 CONTINUE
C
 3000 CONTINUE
      TOMASS=0.
      TPMASS = 0.
      DO 110 J=1,NS
      EFF(J)= (1.-(XNO(J)/ONO(J)))
      DIAM(J) = 2.*RAD(J)*1.0E+06
      OMASS = ONO(J)*DD*4./3.*3.14159*RAD(J)**3*VG
      PMASS = XNO(J)*DD*4./3.*3.14159*RAD(J)**3*VG
      TOMASS=TOMASS+OMASS
      TPMASS = TPMASS + PMASS
  110 CONTINUE
      EFFT=(1-(TPMASS/TOMASS))*100.
  120 NONID = NONID-1
      READ(NREAD,1010)RMMD,RSIG
 1010 FORMAT(2F10.0)
      CALL LNDIST(RMMD,RSIG,PRCR,RPCNT)
      READ(NREAD,1020)NTEMP,SNUCK,ZIGGY,ZNUMS
 1020 FORMAT(I1,9X,3F10.2)
      CONVF = TDK*3670./P
      TEST = .99999
      TSMASS = 0.
      TRMASS = 0.
      DO 204 J=1,NS
      IF(EFF(J).GE.TEST)EFF(J)=TEST
      WY(J) = 100.*VG/ATOTAL*ALOG(1./(1.-EFF(J)))
      IF(SNUCK.NE.0.0)GO TO 201
      IF(ZIGGY.EQ.0.0)GO TO 202
  201 CONTINUE
      PEN = 1.-EFF(J)
      WY(J) = WY(J)/(1.+.0755*ZIGGY*ALOG(1./PEN)+.766*EFF(J)*ZIGGY
     S**1.786)/(ALOG(PEN)/ZNUMS/ALOG(SNUCK+(1.-SNUCK)*PEN**(1./ZNUMS)))
```

```
202 CONTINUE
    IF(DIAM(J).GE.4.4)GO TO 203
    WY(J) = WY(J)*(-4.668-.46*ALOG(2.*RAD(J)))
203 CONTINUE
    EFFS(J) = 1.-EXP(-ATOTAL*WY(J)/100./VG)
    TSMASS = TSMASS + EFFS(J)*PCNT(J)*W
204 CONTINUE
    TEFFS = TSMASS/TOMASS
    EXPON = ALOG(1./(1.-TEFFS))
    XMCLS = CONVF*W/VG*EXP(-EXPON*(PL-PLLS)/PL)*(1.-EXP(-EXPON*PLLS
   S/PL))
    RAPLOS = .618*XMCLS**.894
    IF(NTEMP.EQ.1)RAPLOS=.155*XMCLS**.905
    DO 205 J=1,NS
    EFFR(J) = (PCNT(J)*(1.-EXP(-ATOTAL*WY(J)/100./VG))-RPCNT(J)
   S*RAPLOS/CONVF*VG/W)/PCNT(J)
    IF(EFFR(J).LE.0.0)EFFR(J)=0.0
    TRMASS = TRMASS + EFFR(J)*PCNT(J)*W
205 CONTINUE
    TEFFR = TRMASS/TOMASS
    TOTS = 0.
    TOTR = 0.
    DO 206 J=1,NS
    TOTS = TOTS+PCNT(J)*(1.-EFFS(J))
    TOTR = TOTR+PCNT(J)*(1.-EFFR(J))
206 CONTINUE
    PCUS(0) = 0.
    PCUR(0) = 0.
    DO 207 J=1,NS
    PCNTS(J) = PCNT(J)*(1.-EFFS(J))/TOTS
    PCNTR(J) = PCNT(J)*(1.-EFFR(J))/TOTR
    PCUS(J+1) = PCNTS(J)*100.+PCUS(J)
    PCUR(J+1) = PCNTR(J)*100.+PCUR(J)
207 CONTINUE
    PCUS(NENDPT) = 100.
    PCUR(NENDPT) = 100.
    CALL LNFIT(PCUS,SMMD,SSIG,SGFIT)
    CALL LNFIT(PCUR,RRMMD,RRSIG,RGFIT)
    WRITE(NPRNT,2010)
2010 FORMAT('1CORRECTIONS FOR NONIDEAL CONDITIONS',//'0',6X,'SIZE(UM)'
   S,4X,'INLET FRACT',5X,'NO-RAP EFF',3X,'NO-RAP FRACT',8X,'RAP EFF'
   S,6X,'RAP FRACT'/)
    DO 208 J=1,NS
    WRITE(NPRNT,2020)DIAM(J),PCNT(J),EFFS(J),PCNTS(J),EFFR(J)
   S,PCNTR(J)
2020 FORMAT(' ',6F15.4)
208 CONTINUE
    WRITE(NPRNT,2030)ETAO,EFFT
2030 FORMAT('0STATED EFFICIENCY =',F6.2,5X,'IDEAL CALCULATED EFFICIENCY
   S = ',F8.4/)
    WRITE(NPRNT,2040)D50,SIGMAP
2040 FORMAT('0INLET MMD = ',F5.2,5X,'WITH SIGMA = ',F5.2)
    WRITE(NPRNT,2050)ZIGGY,SNUCK,ZNUMS,NTEMP,RMMD,RSIG
2050 FORMAT('0GAS VELOCITY SIGMA = ',F6.2,' WITH ',F6.2,' SNEAKAGE OVER
   S',F6.2,' STAGES'/' NTEMP = ',I5/' RMMD = ',F5.2,' WITH SIGMA =',
   SF5.2/)
    WRITE(NPRNT,2060)TEFFS,SMMD,SSIG,SGFIT
2060 FORMAT('0ADJUSTED NO-RAP EFFICIENCY = ',F8.4/' NO-RAP OUTLET MMD'
   S,10X,'= ',F8.2/' NO-RAP OUTLET SIGMA',8X,'= ',F8.2/' GFIT',23X,
   S'= ',F8.2/)
```

```
      WRITE(NPRNT,2070)TEFFR,RRMMD,RRSIG,RGFIT
 2070 FORMAT('0EFFICIENCY WITH RAPPING = ',F8.4/' CORRECTED OUTLET MMD'
     $,4X,'= ',F8.2/' CORRECTED OUTLET SIGMA  = ',F8.2/' GFIT',20X,
     $'= ',F8.2)
      IF(NONID.GT.0) GO TO 120
      STOP
      END
```

```
      SUBROUTINE SPCHG1 (SW,ROVRI,DROVRI,XS,ETAPF,DW,QSAT,XNO,A,LSECT,
     1TC,VG,ETAO,FID,AFID,AVGFID,XCD,U,UEO,I,NSECT,LINC,PL,CD,E,ERAVG,
     2NS,XPI)
      REAL LINC
      DIMENSION DW(45),QSAT(20),XNO(20),LSECT(10)
      IF(I.NE.1) GO TO 1286
      SW = 0.0
      ROVRI=10.
      DROVRI=20.0
C
C   COMPUTE VALUE OF EXPONENT IN DEUTSCH EQUATION FOR THE STATED EFF.
C
      XS=ALOG(100./(100.-ETAO))
C
 1286 CONTINUE
C
C   COMPUTE EFFICIENCY PER LENGTH INCREMENT
C
      ETAPF = 1.-EXP(-LINC*XS/PL)
C
C   COMPUTE AMOUNT OF MATERIAL REMOVED PER INCR.ON A TOTAL WEIGHT BASIS
C
      DW(I) = (W - SW) * ETAPF
      SW = SW + DW(I)
      FID=CD/(E*U*ERAVG)
      SUM=0.0
      DO 1300 L=1,NS
 1300 SUM=SUM+QSAT(L)*XNO(L)
      ZC=200.*(DW(I)/W)*(FLOAT(LSECT(NSECT))/TC)*VG*SUM
      ROVRI=ZC+1.0
      AFID=FID/ROVRI
      AVGFID=AFID*1.E-06
      XCD=CD*100000.
C
C   COMPUTE EFFECTIVE MOBILITY
C
      UEO=U/ROVRI
C
      XPI=ETAPF*100.
      RETURN
      END
      SUBROUTINE CHGSUM
      REAL LINC,LTHICK,JPART,JION
      COMMON/BLK5/TDK,NUMSEC
      COMMON/BLK6/VOL(20),XNO(20),Q(20),WS(20),DW(45),AS(10),
     1VOS(10),TCS(10),WLS(10),ACS(10),BS(10),SYS(10),
     2QSAT(20),U,E,EPSO,PI,ERAVG,BC,TEMP,EPS,VAVC
      COMMON/BLK14/TMFP,WY(20),RPCNT(20),PCNTS(20),PCNTP(20),PCOS(21)
     s,PCOR(21)
      COMMON/BLK15/NPRINT,NSECT,SLNGTH,A,VG,TC,B,AC,WL,CL,CD,ET,SY,
     1VGAS,P,VIS,W,LINC,XPI,FPLT,AFID,XCD,ZMD,
     2WT,LTHICK,JPART,JION,I,ROVRI
      COMMON/BLK20/SCHANG,CHRFID,TIMPI,TIMEF,V,FACTRE,RSIZE,CNUMBR,J,
     1ITERR,OLDQF(20),OLDQT(20),SOLDQF(20),SOLDQT(20)
      IF(DVI.EQ.1) GO TO 50
      IF((I.EQ.1).AND.(II.EQ.1)) GO TO 51
      GO TO 52
   51 CONTINUE
      OLDQF(J)=0.
      OLDQT(J)=0.
```

```
   52 CONTINUE
      IF(ITER.NE.1) GO TO 53
      IF(II.GT.1) GO TO 50
      SOLDQF(J)=OLDQF(J)
      SOLDQT(J)=OLDQT(J)
   53 CONTINUE
      IF((ITER.GT.1).AND.(II.EQ.1)) GO TO 54
      GO TO 55
   54 CONTINUE
      OLDQF(J)=SOLDQF(J)
      OLDQT(J)=SOLDQT(J)
   55 CONTINUE
   50 CONTINUE
      IF(NVI.EQ.2) GO TO 56
      IF(I.GT.1) GO TO 56
      OLDQF(J)=0.
      OLDQT(J)=0.
   56 CONTINUE
      SATCHG=E*SCHARG
      IF(OLDQF(J).GE.SATCHG) GO TO 1
      CF1=((CHRFID*U*E)/(4.*EPSO))*(TIMEF-TIMEI)
      CF2=1./(1.-OLDQF(J)/SATCHG)
      QF=SATCHG*((CF1+CF2-1.)/(CF1+CF2))
      IF(QF.GT.SATCHG) QF=SATCHG
      GO TO 2
    1 CONTINUE
      QF=OLDQF(J)
    2 CONTINUE
      OLDQF(J)=QF
      ARG=(V*OLDQT(J))/E
      IF(ARG.GT.30.) GO TO 10
      QT=(E/V)*ALOG(((E**2*RSIZE*VAVC*CHRFID)/(4.*EPSO*BC*TOK))*(TIMEF-
     1TIMEI)+EXP(ARG))
      OLDQT(J)=QT
      GO TO 9
   10 CONTINUE
      QT=OLDQT(J)
    9 CONTINUE
      CNUMBR=(QF+QT)/E
      RETURN
      END
      SUBROUTINE ENDIST (DSO,SIGMAP,PRCU,PCNT)
      DIMENSION Y(100),Z(100),AREA(20),PRCU(21),PCNT(20)
      COMMON/BLK4/NS
      COMMON/BLK11/ENDPT(21),NENDPT
      PI=3.1416
      SIGMAZ=ALOG(SIGMAP)
      N=NS+Z
      NINC=100
      ASUM=0.
      K=0
      DO 240 J=1,N
      IF(J.EQ.1)GO TO 230
      IF(J.EQ.(N))GO TO 232
      X2=ALOG(ENDPT(J))
      X1=ALOG(ENDPT(J-1))
      GO TO 233
  230 CONTINUE
      X1=ALOG(0.01)
      X2=ALOG(ENDPT(J))
```

```
      GO TO 233
232   CONTINUE
      X1=ALOG(ENDPT(J-1))
      X2=ALOG(1000.)
233   CONTINUE
      DX=(X2-X1)/99.
      D=X1
      SGT1=1./(SIGMAZ*(2.*PI)**.5)
      SGT2=2.*SIGMAZ**2
      DO 234 I=1,NINC
      Y(I)=SGT1*EXP(-(D-ALOG(D50))**2/SGT2)
      D=D+DX
234   CONTINUE
      CALL QTFF(DX,Y,Z,NINC)
      ASUM=ASUM+Z(NINC)
      IF(J.LT.N) PRCU(J)=ASUM
      IF((J.EQ.1).OR.(J.EQ.N))GO TO 240
      K=K+1
      AREA(K)=Z(NINC)
240   CONTINUE
      DO 241 I=1,NS
      PCNT(I)=AREA(I)/ASUM
241   CONTINUE
      SUM=0.
      DO 2 I=1,NS
      SUM=SUM+PCNT(I)
2     CONTINUE
      CHECK1 = 1.0 - SUM
      PCNT(NS)=PCNT(NS)+CHECK1
      CHECK2 = 1.0 - PRCU(NENDPT)
      PRCU(NENDPT)=PRCU(NENDPT)+CHECK2
      RETURN
      END
      SUBROUTINE QTFF (DX,Y,Z,NINC)
      DIMENSION Y(100),Z(100)
      SUM2=0.
      IF(NINC - 1) 4,3,1
1     DDX=.5*DX
C
C     INTEGRATION LOOP
      DO2 I=2,NINC
      SUM1=SUM2
      SUM2=SUM2+DDX*(Y(1)+Y(I-1))
2     Z(I-1)=SUM1
3     Z(NINC)=SUM2
4     RETURN
      END
      SUBROUTINE LNFIT (PRCU,D50,SIGMAP,GFIT)
C     THIS SUBROUTINE FITS CUMPERCENT CURVE TO A LOGNORMAL DISTRIBUTION
      DIMENSION Z(21),Y(21),PRCU(21)
      COMMON/BLK11/ENDPT(21),NENDPT
      NSTAG=0
      J=0
      DO 1 I=1,NENDPT
      IF(PRCU(I).LE.0.0)GO TO 1
      J=J+1
      Z(J)=ALOG(ENDPT(I))
      IF(PRCU(I).GE.99.0) GO TO 4
      IF(PRCU(I).GT.50.)GO TO 3
      XX=PRCU(I)/100.
```

```
18100     2      XYY=SQRT(ALOG(1.0/XY**2))
18200            Y(J)=XYY-((2.515517+0.802853*XYY+0.010328*XYY**2)/(1.0+1.432788*X
18300           1YY+0.189269*XYY**2+0.001308*XYY**3))
18400            IF(PRCU(I).GT.50.)GO TO 5
18500            Y(J)=-Y(J)
18600            GO TO 5
18700     3      XY=1.0-(PRCU(I)/100.)
18800            GO TO 2
18900     5      NSTAG=NSTAG+1
19000     1      CONTINUE
          C      CALL CURVE FIT ROUTINE
          4      CALL CFIT(A,B,GFIT,NSTAG,Z,Y)
          C      CALCULATE D50 AND SIGMAP
                 D50=EXP(-A/B)
                 SIGMAP=EXP(1.0/B)
                 RETURN
                 END
                 SUBROUTINE CFIT (A,B,R,NSTAG,Z,Y)
          C      THIS SUBROUTINE FITS A STRAIGHT LINE, Y=A+BX, USING LEAST SQUARES
                 DIMENSION Z(21),Y(21)
                 XN=0.0
                 SUMX=0.0
                 SUMY=0.0
                 SUMXY=0.0
                 SUMXX=0.0
                 SUMYY=0.0
                 DO 6 I=1,NSTAG
                 SUMX=SUMX+Z(I)
                 SUMY=SUMY+Y(I)
                 SUMXY=SUMXY+Z(I)*Y(I)
                 SUMXX=SUMXX+Z(I)**2
                 SUMYY=SUMYY+Y(I)**2
                 XN=XN+1.0
          6      CONTINUE
          C      CALCULATE A,B
                 B=(XN*SUMXY-SUMX*SUMY)/(XN*SUMXX-SUMX**2)
                 A=(SUMXX*SUMY-SUMX*SUMXY)/(XN*SUMXX-SUMX**2)
                 R=SQRT(B*((XN*SUMXY-SUMX*SUMY)/(XN*SUMYY-SUMY**2)))
                 RETURN
                 END
```